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OPERATION OF STABILIZATION PONDS IN A TROPICAL AREA (U)

FINAL REPORT

by

Louis E. Eckley
Larry Canter
George Reid

October, 1974

(For the period 1 July 1968 to 31 December 1973)

Supported by

U.S. ARMY MEDICAL RESEARCH & DEVELOPMENT COMMAND
Office of The Surgeon General, Washington, D.C. 20314
in cooperation with the Commission on Environmental Health
of the Armed Forces Epidemiological Board

Contract No. DADA17-68-C-8137
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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)

6 Operation of Stabilization Ponds in a Tropical Area.

5. TYPE OF REPORT & PERIOD COVERED

9 Final rept.
1 Jul[redacted]968 - 31 Dec [redacted]73,

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)

10 Louis E./Eckley, Larry/Cantor George/Reid

8. CONTRACT OR GRANT NUMBER(s)

15 DADA 17-68-C-8137

9. PERFORMING ORGANIZATION NAME AND ADDRESS

Gorgas Memorial Institute
Gorgas Memorial Laboratory
2007 Eye St., NW
Washington, DC 20006

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS

US Army Medical R&D Command
Washington, DC 20314

12. REPORT DATE

11 Oct[redacted]74

13. NUMBER OF PAGES

ix + 285

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

12 296p.

15. SECURITY CLASS. (of this report)

UNCLAS

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distribution limited to U.S. Government Agencies only, Proprietary Information. June 1971. Other requests for this document must be referred to the Commander, U.S. Army Medical Research and Development Command, (ATTN: SGRD-RP), Washington, DC 20314.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Stabilization Ponds
Wastewater Treatment
Microorganisms
Multiple Regression
Tropical Regions
Faculative Ponds
Multiple Pond Operation
Design Data
Anaerobic Ponds
Maturation Ponds

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study's objective is to provide operating parameters for design of stabilization ponds in tropic areas. Such ponds have the potential to provide a relatively easy to prepare, simple to operate and maintain, method of partial secondary wastewater treatment at low cost. Such ponds are widely used, however, tropical sunlight and temperature conditions are considered primary advantages for an environment for which to better develop design data.

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The contract effort consisted of a series of phases studies. The first studies dealt with single ponds 4-6 ft. (1.25 - 1.87 m) deep. Subsequent studies involved the use of multiple ponds with anaerobic/aerobic modes of operation. Fort Clayton, CZ area wastewaters were used as influents.

A three-pond system, operating in the order anaerobic pond, faculative pond and maturation pond, was the best in terms of removal. Such removals were: BOD_5-75%; COD-60%, organic and ammonia nitrogen-58%; E. coli - 91%. Orthophosphate and nitrate concentrations increased in this and most other configurations employed. A loading limit of 150 lb BOD_5/acre/day (134 Kg BOD_5/ha/day) was suggested.

Multiple regression analysis was used to develop design effluent removals on the basis of influent content, influent-effluent flow, and meteorological considerations.

Special studies were made on the survival of S. typhi in a pond system, shock loadings of selected pesticides, mosquito control, and sludge build-up.

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FOREWARD

This research project was in operation for over five years, thus several persons were involved from its inception to its conclusion. The financial support for the project was from the U. S. Army Medical Research and Development Command. Lt. Col. Roy Reuter has been the project officer at Command since 1971. The contract for the research was with Gorgas Memorial Laboratory, and Dr. Martin Young was the GML officer in charge.

Several military officers were involved in the conduction of the research. Maj. Karl Longley was responsible for iniating the project and remained active in it to 1970. Capt. Lee Ashmore was in charge during 1970, and Maj. Fred Huff during 1971. Capt. Louis Eckley was assigned to the project as his major responsibility from 1971-1974.

From 1972 through July, 1974, two sanitary engineers from the University of Oklahoma, Dr. Larry Canter and Prof. George Reid, served as advisors to the study. The final report is basically the work of Eckley, Canter, and Reid.

Many other persons worked on the project during its lifetime. The most notable is Dr. Miquel Kourany, Gorgas Memorial Laboratory, who conducted the bacteriological analyses.

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Chapter 1

INTRODUCTION

The United States Army has a basic commitment to properly dispose of wastewaters generated at its installations in the continental United States and around the world. Since the effectiveness of most wastewater treatment systems is dependent upon the optimization of biological processes, and since these processes are influenced by the prevailing environmental conditions, the use of similarly designed treatment systems for global installations with differing climates would yield dissimilar effluent qualities. Therefore, treatment system design must be adapted to the climate in the area of application. This is particularly necessary for waste stabilization ponds since they utilize processes which are dependent on natural physical, chemical and biological mechanisms for wastewater quality improvement.

The Army has many installations in tropical areas around the world, and since pond systems provide a low-cost wastewater treatment option, the research project summarized herein was oriented to the development of performance data and design criteria for waste stabilization pond systems in tropical applications. The research was conducted from early 1969 through 1973 on experimental field pond systems located at Fort Clayton in the Canal Zone.

1.1. Background for Study in Canal Zone

During 1966 and 1967, the U. S. Sea-Level Canal Commission conducted surveys to identify possible sea-level canal routes. One of the potential problems which the Sea-Level Canal Commission foresaw was the provision for wastewater treatment at construction base camps and small communities to be located along a new canal. At about the same time, the number of Army installations being built in Vietnam was on the increase, and there was a need for an effective and economical method for treating the wastewaters from these installations. One method for accomplishing the need was believed to be treatment of the wastewater through the utilization of waste stabilization ponds.

A review of the available literature on the design, operation, and effectiveness of stabilization ponds in tropical areas was conducted in 1968. The survey showed that while stabilization ponds had been used in the tropics for years there was very little available information on pond performance. As a result of these findings, an application for research was submitted to the U. S. Army Medical R & D Command. The research project was approved and was to be conducted at a suitable tropical location, which became the Canal Zone, and evaluated over a period of years sufficient to encompass several seasonal cycles. The general purpose of the research project was to determine the stabilization pond design and operational criteria which offered the most efficient and economical means of wastewater treatment for Army installations located in the tropics.

1.2. Unique Wastewater Treatment Requirements at Army Installations

Military installations often have a short-term existence and are relatively small in troop size, thus wastewater treatment considerations are directed toward low-cost processes that can be easily constructed and placed into operation, and rapidly removed or abandoned when the military requirement is terminated. An important corollary concern is the protection of public health through the removal of pathogenic organisms from wastewaters prior to disposal. In contrast to small, temporary installations, wastewater treatment needs also encompass large, permanent facilities. In addition, even permanent facilities may have variations in troop strength, thus causing wastewater flow and organic loading variations on treatment systems.

Another unique feature of wastewater treatment needs at Army installations results from variations of wastewater flows and quality characteristics due to infiltration or exfiltration in sewer systems. The wastewater may also contain excessive concentrations of pesticides, motor pool oils and hospital wastes. Pesticides and oils may exhibit toxicity to bacterial systems, and hospital wastes can contribute excessive or unique pathogenic organisms.

Finally, effluent quality standards vary with location in the continental United States. Effluent standards may be less restrictive to non-existent in many global installations.

1.3. Objective of Project

The broad objective of this research project as delineated upon its inception in 1969, was as follows:

To investigate and define ---

1) The roles of physical, chemical, and microbiological parameters in relation to operation of stabilization ponds in tropical areas. Particular emphasis will be placed upon waste material characteristics and loadings, dissolved oxygen, algae type and production, and the influence of temperature and the relatively high intensity sunlight of tropical areas.

2) The effect of stabilization pond environmental conditions on the viability of certain enterobacterial pathogens.

3) The effects of various detention periods, water depths, and loading fluctuations upon the operation and performance of stabilization ponds in tropical areas.

4) Maximum acceptable loading limits, in terms of 5-day, 20°C biochemical oxygen demand (BOD) in relation to design and operating parameters.

Specific sub-objectives added in 1971 and conducted in 1972-73 involved testing a single pond to organic loading failure, and the study of a two-cell pond system. Sub-objectives added in 1972 and accomplished in 1973 included study of a three-cell pond system and conduction of bench-scale experiments on selected health aspects of pond operation. The health-related experiments were directed toward the fate of *Salmonella typhi* in ponds, the fate and influence of pesticides in ponds, and the dispersion of *Escherichia coli* in a receiving stream for the pond effluent. The receiving stream for the Fort Clayton ponds was the Panama Canal just downstream from the Miraflores Locks.

1.4. Organization of Report

This report is organized into a series of chapters. Chapter 2 contains a review of literature on the applications, design and effectiveness of ponds. Chapter 3 has a discussion of the five-year experimental program and a summary of the operational results. Presentation of mathematical analyses of the field data is made in Chapter 4, including summary predictive and design relationships for the single and multi-cell pond systems. Finally, Chapter 5 contains a summary of the project results and a series of conclusions. The basic five chapters are supported by a bibliography and appendices containing collected and reduced data.

Chapter 2

LITERATURE REVIEW

This chapter contains a summary of the use of waste stabilization ponds as a method of wastewater treatment. Although this research project was oriented to ponds in tropical areas, the literature review is focused on pond research and usage throughout the world. The chapter is divided into sections dealing with general information, the stabilization process, bacteria in ponds, algae in ponds, viruses in ponds, higher life forms in ponds, nutrient removals, the effects of climatic conditions, design consideration, pond effluent quality, operation and maintenance, and cost considerations.

2.1. General Information

Waste stabilization ponds may be defined as shallow, diked structures designed specifically to accomplish wastewater treatment by natural biological, chemical and physical processes. Although holding ponds and other lagoon facilities have purified wastewater by natural processes for many years, it is considered that the first pond constructed according to sound engineering principles was built in Maddock, North Dakota, in 1948 (Porges and Mackenthun, 1963).

Since 1948, ponds have gained wide acceptance, both in the United States and in many other parts of the world, as a method of municipal and industrial waste treatment. In 1957, 27 states of the

United States had a total of 430 ponds serving the wastewater treatment needs of 760,000 persons. By 1962, the number had increased to over 1300 ponds in 39 states benefitting a population of more than 2 million persons (Wright, 1966). A survey made by the U.S. Public Health Service in 1963 disclosed that 31 industrial groups were using 847 waste stabilization ponds as a means of treating their wastes (Porges and Mackenthun, 1963). In 1966 more than 1200 municipal and industrial ponds were serving the State of California alone (McGauhey, 1968). According to a 1971 inventory, there was a total of about 4500 municipal ponds in use in the United States (Barsom, 1973). This total does not include private ponds which serve individual homes, trailer parks, schools, shopping centers, gas stations and other facilities.

Gloyna (1971) indicated that ponds were in use in 39 countries in the world, including the United States. The data was for the period 1964-67. The list of countries included Argentina, Australia, Bolivia, Brazil, Canada, Colombia, Costa Rica, Cuba, Ecuador, Federal Republic of Germany, Finland, German Democratic Republic, Ghana, Guatemala, India, Israel, Japan, Kenya, Mauritius, Mexico, Netherlands, New Zealand, Nicaragua, Nigeria, Pakistan, Peru, Romania, Saudi Arabia, South Africa, Southern Rodesia, Sweden, Thailand, Trinidad and Tobago, Uganda, Union of Sovient Socialist Republics, United Arab Republic, United States of America, Venezuela, and Zambia. Ponds were in use from the polar areas to the equator.

Utilization of 181 pond installations in Latin America was reported in 1971 by the Pan American Center for Sanitary Engineering and Environmental Sciences (Talboys, 1971). Latin American countries not included in Gloyna's list (1971) were Chile, El Salvador, Panama and Canal Zone, Barbados, Dominican Republic, Honduras and Uruguay. Three pond systems were reported in Panama and the Canal Zone. Single ponds treating piggery wastes were located in San Juan and Gatuncillo, Panama; and the experimental ponds reported on in this study were located at Ft. Clayton in the Canal Zone.

The phenomenal growth in pond applications clearly indicates that waste stabilization ponds have a place in wastewater treatment. One factor in the increase in use has been flexibility of pond applications. Ponds may be used as primary, secondary, or tertiary treatment of both municipal and industrial wastewaters. To distinguish between the more common types of ponds, the following definitions are presented:

1) Waste Stabilization Pond - A basin used to treat organic wastes by natural biological, biochemical, and physical processes commonly referred to as "self purification" (Wright, 1966). The terms "waste stabilization pond" and "facultative waste stabilization pond" are often used interchangeably. Waste stabilization ponds are also referred to as oxidation ponds or lagoons.

2) Aerated Lagoon - A pond, commonly 6 to 15 ft. deep, in which the principle source of oxygen is furnished by diffused or mechanical aeration rather than photosynthesis (Eckenfelder, 1966).

3) Aerobic Pond - A shallow depression, approximately 18 inches deep, in which the suspended and dissolved degradable substances are stabilized by an aerobic microbial population. The biota are supplied

with required oxygen by algal photosynthesis as well as by gas transfer at the pond surface (Fair, Geyer, and Okun, 1968).

4) Anaerobic Pond - A relatively deep basin (6-15 ft.) in which the major portion of the BOD is reduced through methane formation. The process of degradation is essentially that of anaerobic digestion (Oswald, 1960). These ponds may be used singly or prior to other ponds in a series (pretreatment).

5) Facultative Pond - A waste stabilization pond of moderate depth (3-6 ft.) which is divided by loading and thermal stratification into distinct surface and bottom zones incorporating the mechanisms of aerobic and anaerobic degradation, respectively. This is by far the most widely used pond for the treatment of municipal wastewaters. A facultative pond receiving untreated wastewater may be referred to as a raw or primary waste stabilization pond, and the second pond in a series may be referred to as a secondary waste stabilization pond (Gloyna, 1971).

6) Maturation Pond - A pond, usually last in a series, whose primary function is the reduction of disease-causing microorganisms through extended detention time (Gloyna, 1971). A maturation pond may be utilized for fish production.

Recently, several extensive reviews of the state-of-the-art of ponds have been published (Canter, 1969; Caglayan, 1970; Gloyna, 1971; Missouri Basin, 1971; and Barsom, 1973). Canter included a literature survey in conjunction with a study of pond design criteria and experimental pond performance in Colombia (Canter, 1969). Caglayan described the theories associated with pond design and operation, particularly as related to Middle East applications (Caglayan, 1970). Gloyna summarized global information on waste stabilization ponds for the World Health Organization (Gloyna, 1971). The Missouri Basin Engineering Health Council conducted a state-of-the-art survey of the design of facultative ponds, aerated lagoons, and anaerobic ponds (Missouri Basin, 1971). Barsom's study was oriented to factors limiting pond performance and the impact of pond effluents on receiving water quality (Barsom, 1973).

The Second International Symposium for Waste Treatment Lagoons was held in Kansas City in 1970, and the proceedings are available (McKinney, 1970). The first Symposium was held in 1961. Information from both symposia is included in this review.

2.2 The Stabilization Process

Algae and bacteria exist in a symbiotic relationship in waste stabilization ponds. Bacteria perform the same function in ponds as they do in other biological waste treatment processes; that is, they degrade organic material. A typical representation of the aerobic bacterial decomposition of organic material is indicated in Reaction 1.

$$6(CH_2O)_x + 5O_2 \longrightarrow (CH_2O)_x + 5CO_2 + 5H_2O + \text{energy} \qquad \text{(Re. 1)}$$

As denoted in Reaction 1, organic material, represented as carbohydrates $6(CH_2O)_x$, is converted into bacterial cells $(CH_2O)_x$, carbon dioxide and water. The released energy is used in the synthesis of new cells. Dissolved oxygen is used as the electron acceptor and, as a result, is consumed. Although not included in Reaction 1, soluble inorganic materials such as nitrates, phosphates, and sulfates are returned to solution from the organic material in the wastewater.

Algae in waste stabilization ponds perform the function of providing some of the oxygen required by bacteria for aerobic decomposition. The other major portion of the required oxygen would come from surface reaeration. Chemically bound oxygen is the primary oxygen source for anaerobic ponds. It has been estimated that algae can supply from 125-250 lb. of O_2 per acre per day, whereas surface reaeration can supply up to 40 lb. of O_2 per acre per day. Therefore, from an oxygen source standpoint, photosynthetic oxygenation can supply from three to six times as much oxygen as can surface reaeration. A typical representation of photosynthetic oxygenation is listed in Reaction 2.

$$CO_2 + H_2O + \text{inorganics} + \text{light} \longrightarrow (CH_2O)_x + O_2 + \text{energy} \quad \text{(Re. 2)}$$

New algae cells $(CH_2O)_x$ are formed from inorganic materials in the presence of sunlight. In this process, dissolved oxygen is generated.

When the dissolved oxygen supply is not sufficient for maintaining aerobic conditions, anaerobic degradation will occur. Anaerobic degradation occurs by a two-step process: 1) organic acid production and 2) methane production. Organic acid generation is represented by Reaction 3, and methane production by Reaction 4 (Oswald, 1968).

$$5(CH_2O)_x \longrightarrow (CH_2O)_x + 2CH_3COOH + \text{energy} \qquad \text{(Re. 3)}$$

$$2\tfrac{1}{2}CH_3COOH \longrightarrow (CH_2O)_x + 2CH_4 + 2CO_2 + \text{energy} \qquad \text{(Re. 4)}$$

Organic acids can be oxidized to carbon dioxide and water in the presence of dissolved oxygen. This type of oxidation is indicated in Reaction 1. Aerobic oxidation of organic acids can occur in the oxygen-containing layer overlying the anaerobic layer in a facultative pond. A summary of the required conditions or levels for each of the above four reactions is shown in Table 2.1. (Oswald, 1968).

2.3. Bacteria in Ponds

Waste stabilization ponds contain a variety of bacterial species, including obligate aerobes, facultative aerobes and obligate anaerobes. McKinney (1962) reported on the presence of *Pseudomonas*, *Flavobacterium*, and *Alcaligenes* in ponds. Gann, et al. (1968), indicated that *Achromobacter*, *Pseudomonas*, and *Flavobacterium* are the predominant bacterial species in both laboratory and field ponds. Coliform organisms, *Streptococcus faecalis*, and sporeformers of the genus *Bacillus* may also be present. Sulfate-reducing bacteria, "acid-formers" and "methane producers" are groups of anaerobic bacteria which are also present in facultative and anaerobic ponds. Optimum aerobic bacterial populations are in the order of 10^{10} per ml. (Oswald, 1968).

TABLE 2.1: REQUIRED CONDITIONS OR LEVELS FOR INDICATED BIOLOGICAL REACTION IN PONDS

Environmental Factors	Aerobic Oxidation (Re. 1)			Algal Photosynthesis (Re. 2)			Organic Acid Formation (Re. 3)			Methane Fermentation (Re. 4)		
	Min.	Opt.	Max.	Min.	Opt.	Max.	Min.	Opt.	Max.	Min.	Opt.	Max.
Population	Aerobic bacteria			Chlorella, Scenedesmus			Heterotrophs facultative			Mesophilic bacteria		
(No. per ml.)	10^8	10^{10}	10^{12}	10^5	10^7	10^8	10^8	10^{10}	10^{12}	Unknown		
Nutrients	Carbohydrate, protein, fat			CO_2, ammonia, P, S			Carbohydrate, protein, fat			Organic acids, alcohols		
Oxygen (mg/l)	1	10	30	Unknown			0	0	1	0	0	0
Temperature, °C.	15	25	40	4	25	40	4	25	40	15	32	40
pH	6.5	8.0	10.0	7.0	8.5	10.8	4.3	6.5	7.5	6.8	7.0	7.2
Alkalinity (mg/l)	-	200	-	-	300	-	Unknown			500	2000	-
Antecedent reactions	Photosynthesis			Oxidation			Organic synthesis			Organic acid formation		
Competitive reactions	Sedimentation, methane fermentation			Autoflocculation			Oxidation			Oxidation		
Predators	Unknown			Rotifera, Cladocera			Unknown			Unknown		
Toxic substances	Salts, heavy metals			Copper, chromium			Salts, heavy metals			Oxygen, copper, salt, chromium, heavy metals		
Energy source	Nutrients			Light			Nutrients			Nutrients		
Redox potential E_n mv	+0.2	0.5	-	+0.5	Unknown	-	-0.1	-	+0.2	-0.10	-0.5	-

2.3.1. Major Genera

In the aerobic layer of laboratory ponds, Gann, et al. (1968), reported that *Achromobacter* accounts for 65% of the total bacteria; *Pseudomonas*, 25%; and *Flavobacterium*, 5%. These relative proportions were also found in field ponds near Oklahoma City, Oklahoma, with organic loadings ranging from 15-60 lb. BOD/acre/day.

Jourdan (1969) indicated that the major genera in untreated Colombian wastewater included *Achromobacter* (78% of the total), *Pseudomonas* (11%), and *Flavobacterium* (6%). Treated Colombian wastewater had 82% *Achromobacter*, and 7% each *Pseudomonas* and *Flavobacterium*. The low percentage of *Pseudomonas* in relation to Gann's results (Gann, et al., 1968) was probably due to the relative dearth of proteinaceous material in the South American wastewater.

Ganapati and Amin (1972) recently reported on the microbiology of the viscous scum that always develops on the surface of a pond within the first few days after start-up. Zoogleal strains were found, with these being similar to those found in activated sludge flocs.

2.3.2. Odors Due to Bacterial Action

Odors may be produced in ponds as a result of bacterial action under anaerobic conditions. Organic acid odors and hydrogen sulfide odors result from acid formation, and hydrogen sulfide odors result from methane fermentation (McGauhey, 1968).

2.3.3. Fate of Pathogenic Bacteria

The fate of pathogenic organisms in waste stabilization ponds is of major interest due to public health considerations. Bacteria, protozoa, viruses, nematodes, and fungi are some of the organisms in wastewaters which can cause infectious diseases. Waste stabilization ponds usually do not have separate disinfection facilities, and any disinfection which occurs is from natural causes.

Specific determinations of pathogenic bacteria are not routinely conducted due to procedural complexities. Indicator organisms are used, with the most common being total coliforms, fecal coliforms and *Escherichia coli*. Other bacteria such as *Salmonella* have been periodically studied. Many observations have been made on the percentage removals of coliforms and *Salmonella* in both laboratory and field ponds, including those by Towne and Davis (1957), Clare (1961), Malina and Yousef (1964), Cody and Tischer (1965), Marais (1966), Gann, et al. (1968), McGarry and Bouthillier (1968), Mauldin (1968), Jourdan (1969), Moawad and El-Baroudi (1969), Klock (1971), Georgia Water Quality Control Board (1971), and Slanetz, et al. (1972).

A number of theories have been suggested to describe the mechanisms involved in pathogen removal in ponds. McKinney (1962) suggested that competition for nutrients between the parasitic pathogens and the normal saprophytes is a major factor. This concept implies that better pathogen removals will occur at lower organic loading rates. Extensive bench-scale studies by Mauldin (1968) confirmed competition for nutrients as the major removal mechanism. Other theories suggested include bacterial die-away due to: the high pH resulting from utilization of carbon dioxide by algae, algal production of materials toxic to some bacteria, and the bactericidal effect of sunlight (Pratt, 1944). Bacteriophages have also been found to be selective against *E. coli* and *A. aerogenes*, and these phages may be responsible in part for the destruction of coliform organisms.

Several equations which describe pathogenic organism removals in ponds have been developed. Malina and Yousef (1964) advocated the empirical relationship shown in Equation 1.

$$100 - P.R. = \frac{100}{KR + 1} \qquad \text{(Eq. 1)}$$

where:

P.R. = removal of pathogenic bacteria (%)

K = reaction constant

R = detention time (days)

Marais (1966) suggested Equation 2 for a single pond and Equation 3 for two ponds in series. Equation 2 is the same as the Malina-Yousef equation.

$$100 - P.R. = \frac{100}{KR + 1} \qquad \text{(Eq. 2)}$$

$$100 - P.R. = \frac{100}{(kR_1 + 1)(KR_2 + 1)} \qquad \text{(Eq. 3)}$$

where:

P.R. = removal of pathogenic bacteria (%)

K = 2.0 (*Esch. coli*)

= 0.8 (*S. typhi*)

R_1 = detention time (days) in pond 1

R_2 = detention time (days) in pond 2

Mauldin (1968) derived Equations 4 and 5 based on laboratory observations of the influence of organic loading, detention time, and pond depth on pathogen removal.

$$P.R. = \frac{(100)(K')\ R^{0.04}}{L^{0.306} D^{0.0033}} \qquad \text{(Eq. 4)}$$

$$K' = 0.0089\ L + 2.55 \qquad \text{(Eq. 5)}$$

where: P.R. = removal of pathogenic bacteria (%)

K' = proportionality constant

L = organic loading rate (lb. BOD/ac./day)

D = pond liquid depth (ft.)

R = detention time (days)

2.4. Algae in Ponds

Algae is the collective name for microscopic plants which have chlorophyll and exhibit true photosynthesis. Photosynthesis (using light as the energy source for cell synthesis) is the process that converts simple, stable, inorganic compounds into an energy-rich combination of organic matter and oxygen (Rabionwitch and Govindjee, 1965).

It has been estimated that more than 20,000 algae species can survive and grow in aqueous environments (Palmer, 1962); however, in waste stabilization ponds, environmental conditions limit the number of predominant algae species to less than twenty-five. Palmer (1962) defined four groups of algae: blue-green, green, diatoms, and pigmented flagellates. Table 2.2 contains a list of some of the characteristics of the algae in each of the groups. A list of reported algal species in ponds is contained in Table 2.3. Of the species included

TABLE 2.2: CHARACTERISTICS OF FOUR MAJOR ALGAL GROUPS (after Palmer, 1962)

Characteristic	Algal Group			
	Blue-green	Green	Diatoms	Pigmented Flagellates
Color	blue-green to brown	green to yellow-green	brown to light green	green or brown
Location of pigment	throughout cells	in plastids	in plastids	in plastids
Starch	absent	present	absent	present or absent
Cell wall	inseparable from slimy coating	semirigid smooth or with spines	very rigid, with regular marking	thin, thick, or absent
Nucleus	absent	present	present	present
Flagellum	absent	absent	absent	present
Eye spot	absent	absent	absent	present

TABLE 2.3: OBSERVATIONS ON ALGAL SPECIES IN WASTE STABILIZATION PONDS

Algal group Palmer (1962)	Algal species	References*
Blue-green	Anabaena	(1)
	Anacystis	(1)
	Oscillatoria	(1)
	Phormidium	(1)
	Spirulina	(2)
Green	Ankistrodesmus	(1),(3),(2)
	Chlorella	(4),(1),(5),(3),(6),(2)
	Cladophora	(7)
	Micractinium	(1),(8),(6),(2)
	Palmellococcus	(9)
	Scenedesmus	(1),(8),(9),(3),(6)
	Spirogyra	(4)
	Ulothrix	(4)
	Vaucheria	(4)
Diatoms	Navicula	(6)
Pigmented Flagellates	Chlamydomonas	(1),(5),(3),(6)
	Euglena	(4),(1),(8),(9),(3),(6),(2)
	Rhodomonas	(9)

*1. Gloyna (1968)
2. Marais (1966)
3. Mackenthun (1964)
4. McKinney (1962)
5. Fisher (1968)
6. Wilson (1960)
7. Svore (1968)
8. Mills (1962)
9. Thirumurthi and Nashashibi (1967)

in this list, the most frequently occurring are *Ankistrodesmus*, *Chlorella*, *Micractinium*, *Scenedesmus*, *Chlamydomonas*, and *Euglena*.

2.4.1. Photosynthesis and Respiration

The light energy utilized in photosynthesis is mainly in the red portion of the visible spectrum, and specifically in the wavelength range between 4000 Å and 7000 Å (Rich, 1963). The light energy is absorbed by the colored pigments in the algae cells, and then the absorbed energy is transferred to the chlorophyll molecules within the cells. The efficiency of solar energy conversion into useable photosynthetic energy was estimated to be 2-4% by Rich (1963), while Herman and Gloyna (1958) indicated a utilization efficiency of 2-9%, with 5% being common.

2.4.2. Environmental Requirements of Algae

Environmental factors affecting algae have been classified by Pipes (1961) into three major groups: 1) physical, 2) chemical, and 3) biological.

The major physical factors are light (solar radiation) and temperature. The rate of photosynthesis increases as light intensity increases to a point; then over a certain range of intensity the rate of photosynthesis is constant; and finally, for very high intensities, the rate of photosynthesis decreases with increasing light intensity. The independent range extends from about 500 to 5000 ft.-candles.

The solar energy available for photosynthetic utilization is a function of geographical location (latitude), elevation, season, and meteorological conditions. The greatest amount of solar energy is available at the equator, with this amount decreasing toward the poles. The available solar energy at any geographical location increases with increasing elevation above sea-level. There is an annual variation in available solar energy due to seasonal conditions; that is, more solar energy is available in the summer than in the winter in the northern hemisphere. The meteorological condition most affecting sunlight is the degree of cloudiness. There is less solar energy available on cloudy days than on clear days.

The permissible water temperature range for algae growth is from $4^{\circ}C$ to $40^{\circ}C$ (Oswald, 1968; McGauhey, 1968). The optimum range is between $18^{\circ}C$ and $40^{\circ}C$, depending on the algae group (Palmer, 1962). The optimum range for diatoms is $18^{\circ}C$ to $30^{\circ}C$, for green algae it is $30^{\circ}C$ to $35^{\circ}C$, and for blue-green algae it is $35^{\circ}C$ to $40^{\circ}C$.

The major chemical factors are nutritional substances, pH, and toxic materials (Pipes, 1961). The nutritional requirements for algae are: 1) an energy source (sunlight), 2) macronutrients, 3) micronutrients, and 4) certain specific organic structures known as growth factors. The quantity required by the algae distinguishes between macronutrients and micronutrients, not the concentration of these elements in the water. The required macronutrients include carbon, hydrogen, oxygen, nitrogen, phosphorus, and potassium (constituent of algae cell sap). The required micronutrients include iron, magnesium (constituent of chlorophyll), calcium, boron, zinc, copper, manganese, cobalt, molybdenum, and others (Pipes, 1961; Varma and Talbot, 1965).

Algae can utilize inorganic nitrogen in the ammonia (NH_3) form, the nitrite (NO_2^-) form, or the nitrate (NO_3^-) form. The nitrate form seems most conducive to algae growth.

The pH of a water environment greatly affects the biological activity therein. Most biological organisms exhibit optimum growth in certain pH ranges. Photosynthetic oxygenation occurs best between pH 6.5 and pH 10.5, all other factors being equal (McGauhey, 1968).

Almost any chemical substance will be toxic to algae if present in sufficient concentration. Gloyna (1968) presented information on the toxic effects of several organic chemicals on Chlorella pyrenoidosa. Reid and Assenzo (1961) reported that ferric oxide (Fe_2O_3) in concentrations greater than 5 mg/l is toxic to algae. McGauhey (1968) indicated that calcium, chlorine, copper, and chromium are substances which can be toxic to algae.

2.4.3. Composition of Algae

Several empirical formulas and the percentage composition of the basic elements of algal cells are indicated in Table 2.4. Based on algae composition and Reaction 2, Rich (1963) indicated that from 1.25 to 1.75 gm. O_2 is produced per gm. of algae synthesized. With satisfactory illumination, temperature, and nutrition, photosynthetic oxygenation may give rise to 200-250 lb. O_2 per acre per day (Mackenthun, 1964).

2.4.4. Effects on Pond Characteristics

Algae can exert an effect on several characteristics of the liquid in waste stabilization ponds, including pH, alkalinity, hardness,

TABLE 2.4: ELEMENTAL COMPOSITION OF ALGAE

Empirical formula	Elemental Composition (%)					References**
	C	H	O	N	P	
$C_5H_8O_2N$*	52.63	7.02	28.07	12.28		(1)
$C_{5.7}H_{9.8}O_{2.3}N$*	53.02	7.60	28.53	10.85		(1)
$C_{.06}H_{180}O_{45}N_{16}P_1$	52.41	7.42	29.66	9.23	1.28	(2)
$C_{7.62}H_{8.08}O_{2.53}N$	59.38	5.25	26.28	9.09		(3)
	49-70			1.4-11	0.9-2.0	(4)

*Chlorella

**References --
1. McKinney (1962)
2. Gloyna (1968)
3. Cooper (1968)
4. Bogan (1962)

turbidity and color (Palmer, 1962; McKinney, 1962). During peak photosynthetic activity, algae may utilize carbon dioxide from the natural carbonate buffer system. The resultant hydroxyl ions (OH^-) cause an increase in pH, perhaps as high as pH 10 or 11, during the daylight hours. During nonphotosynthetic periods such as the night-time, the pH returns to near neutrality. Since the predominance of the three components of alkalinity (HCO_3^-, $CO_3^=$, OH^-) is a function of the pH, diurnal variation of pH will cause a corresponding variation of alkalinity. Oswald (1968) indicated that 300 mg/l alkalinity is required to support algae growth. Some hardness removal may also occur due to precipitation of $CaCO_3$ at the high pH values which occur. Vigorous algae growths have decreased water hardness by as much as one-third (Palmer, 1962). As substances begin to precipitate at high pH, this may cause flocculation and subsequent settling of algae and bacteria (Oswald, 1968; Pipes, 1961). Dense algal growths increase the turbidity of pond water. Algae usually impart a characteristic green color to water.

2.4.5. Algae Predators

Several biological species are predatory to pond algae. *Rotifera* and *Cladocera* are predators indicated by Oswald (1968). In ponds subjected to organic loadings of less than 10 lb. BOD/acre/day, algae may be consumed by *Daphnia* and *Cyclops* (Gloyna, 1968). Wilson (1960) found that water fleas such as *Daphnia longispina* could feed on algae and cause an almost complete disappearance of it. Some algal cells may settle to the pond bottom and be consumed by Chironomus larvae (Gloyna, 1968). A recent study in Texas was directed toward the controlled utilization of Daphnia for pond effluent quality control (Dinges, 1973).

2.5. Viruses in Ponds

The removal of viruses in ponds has not been as extensively investigated as the die-away of bacteria. Publications which appeared as early as 1951 cited the isolation of enteric viruses from wastewater, however, much remains to be learned about quantitative evaluations (Clark, et al., 1951; Chin, et al., 1965).

Englande, et al., (1965) conducted a virologic study on waste stabilization ponds at Santee, California. The Santee treatment system involved primary settling, an activated sludge unit, retention in a 16-acre pond with a detention time of approximately 30 days, filtration through a natural sand and gravel layer, and chlorination. An average virus removal of 91% was reported for a 3-year study. Virus reduction in ponds are due primarily to the long detention times.

The fate of enteric viruses in three New Hampshire pond systems was recently reported on by Slanetz, et al. (1972). Enteric viruses were isolated from a majority of the effluent samples from these ponds during all seasons.

2.6. Higher Life Forms in Ponds

Waste stabilization ponds may support transient organisms such as water fowl, rodents and those forms having aquatic phases in their life cycles. Water fowl are of concern in some instances because of the possibility of the spread of disease through migration. Duck, fish, otters, beavers, and rodents may utilize ponds as resting, feeding and nesting places (Clare, 1961).

A recent study revealed 60 species of aquatic insects in 18 central Missouri ponds (Kimberle and Enns, 1968). One or more of three species of midges, Glyptotendipes barbipes, Chironomus plumosus, and Tanypus punctipennis comprised more than 94% of the total number of collected insects. Predominant mosquito species observed include Culex tarsalis and Culex pipiens (the primary vectors of encephalitic diseases). It has been found that emergent vegetation is the principal factor conducive to mosquito breeding in ponds (Kimberle and Enns, 1968).

The dominant protozoa in ponds varies primarily with organic loadings. Near the inlet the flagellate Chilamonas is found, but it yields to the free-swimming ciliates such as Colpidium, Paramecium, Glaucoma, and Euplotes. With increased bacterial populations the stalked ciliates Vorticella and Epistylis occur. In ponds with loadings of less than 10 lb. BOD/acre/day, higher animal forms such as Daphnia, Rotaria, and Cyclops may flourish (McKinney, 1962).

2.7. Nutrient Removals

The removal of inorganic nitrogen (NH_3, NO_3^-, NO_2^-) in ponds may exceed 90% in the summer (MacKenthun, 1964). For algae grown on domestic wastewater, nitrogen may be limiting with respect to the sources of phosphorus and carbon.

Due to relative cell compositions, algae can better remove phosphorus from wastes than bacteria; however, the removal rate is lower. Phosphorus removals in ponds have been reported as erratic, ranging from 10% to 90% (Bogan, 1962). The mechanisms of phosphorus removal in ponds are by metabolic uptake and by chemical coagulation of phosphorus followed by adsorption on the algal cells. Pipes (1961) has indicated that the high pH in ponds cuases monobasic and dibasic acid phosphate ions to be converted to orthophosphate ions, and then calcium phosphate precipitates.

Reid and Assenzo (1965) reported on the removals of nitrogen and phosphorus in several central Oklahoma ponds. The optimum nitrogen to phosphorus ratios for nutrient removal varied from 5 to 1 to 10 to 1; the BOD to phosphorus ratio varied from 16 to 1 to 78 to 1. Nitrogen and phosphorus removals for the seven ponds in the study ranged from 30 to 95%.

2.8. Effects of Climatic Conditions

The major climatic conditions which affect pond performance are temperature, solar radiation, and windspeed.

2.8.1. Temperature

Temperature affects the rate of algal and bacterial metabolism and hence the rate of photosynthesis and organic degradation. Hermann and Gloyna (1958) reported that in latitudes with negligible winter ice cover, temperature may be much more influential in determining pond efficiency than available light energy since sufficient solar radiation would be available throughout the year.

Temperature also affects pond performance in still a different manner. Algal cells acting as black bodies increase pond effectiveness in the absorption of light. Since algae use less than 10% of this light energy for photosynthesis, the remainder is absorbed as heat and the upper layers of ponds are readily warmed. The resultant relatively warm, less dense surface waters resist mixing with the cooler, denser waters beneath, and thermal stratification may occur. The waters above the thermocline contain dissolved oxygen in varying amounts; whereas, the waters below rarely contain any dissolved oxygen except during periods of strong winds. Facultative ponds must maintain the integrity of these two zones to prevent dissolved oxygen interference with benthal digestion.

2.8.2. Solar Radiation

Solar radiation is used by algae as the energy source in the process of photosynthesis. The available solar radiation at a given location is a function of latitude, season of the year, elevation, and cloud cover. Table 2.5 contains the probable values of visible solar energy as a function of latitude and energy (Oswald and Gotaas, 1955). From Table 2.5 it can be seen that the available solar energy on a bright day in the temperate zone is about 300 Langleys (9000 ft.-candles).

The euphotic zone, that is the zone in which light penetration is effective in photosynthesis, may vary from a few inches to a depth

TABLE 2.5: PROBABLE VALUES OF VISIBLE SOLAR ENERGY AS A FUNCTION OF LATITUDE AND MONTH

Latitude		Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
0	max	255*	266	271	266	249	236	238	252	269	265	256	253
	min	210	219	206	188	182	103	137	167	207	203	202	195
10	max	223	244	264	271	270	262	265	266	266	248	228	225
	min	179	184	193	183	192	129	158	176	196	181	176	162
20	max	183	213	246	271	284	284	282	272	252	224	190	182
	min	134	140	168	170	194	148	172	177	176	150	138	120
30	max	136	176	218	261	290	296	289	271	231	192	148	126
	min	76	96	134	151	184	163	178	166	147	113	90	70
40	max	80	130	181	181	286	298	288	258	203	152	95	66
	min	30	53	95	125	162	173	172	147	112	72	42	24
50	max	28	70	141	210	271	297	280	236	166	100	40	26
	min	10	19	58	97	144	176	155	125	73	40	15	7
60	max	7	32	107	176	249	294	268	205	126	43	10	5
	min	2	4	33	79	132	174	144	100	38	26	3	1

*Values of S in Langleys, cal/(cm^2) (day)

Correction for cloudiness:

$$S_c = S_{min} + r(S_{max} - S_{min})$$

where:

r = total hours sunshine/total possible hours sunshine

Correction for elevation up to 10,000 ft.:

$$S_c = S(1 + 0.01e)$$

where:

e = elevation in hundreds of feet

of up to 3 feet depending on climatic conditions. Towne and Davis (1957), while studying ponds in the Dakotas, found that only 1% of surface light penetrated the upper 6 inches. It is therefore apparent that only a small fraction of the pond volume actually contributes to oxygen production. Added emphasis is thus placed on vertical mixing induced by wind.

2.8.3. Windspeed

Wind is important in promoting surface reaeration, and wind can also cause surface de-aeration under supersaturated conditions with respect to dissolved oxygen. However, the most important function of wind is in the promotion of mixing of the pond contents (Watters, et al., 1973).

A minimum of work has been done on the quantitative requirements of windspeed for the promotion of mixing. The wind velocity required for mixing is considered to be related to pond size (Towne and Davis, 1957). In the midwestern United States, an exposed water distance of 650 feet will usually insure circulation in a pond with a depth of 3 feet (Hopkins and Hopkins, 1961).

Excessive windspeeds can create wave action within ponds, and these waves may accelerate erosion of pond levees at the waterline. In North and South Dakota, pond water surfaces will resist wave formation when windspeeds are less than 30 mph (Towne and Davis, 1957).

2.9. Design Considerations

The engineering design of a waste stabilization pond is critical to satisfactory operation and treatment efficiency. The approach to design depends upon whether the pond is a single or multi-cell system, and whether it is to be an aerobic, a facultative, or an anaerobic facility, or some combination thereof. The two approaches in design are to: 1) use design criteria basically developed from satisfactory operating experience, and 2) use empirical design equations which have been developed from experimentation.

2.9.1. Design Criteria Based on Usage

The most critical design parameter for waste stabilization ponds is the organic loading rate. The allowable organic loading is a function of the rate at which biological processes can satisfactorily decompose the organic matter without creating nuisance conditions. This rate is a function of a number of climatic variables, with temperature being the most important. Towne and Horning (1960) reported on the influence of ice cover and open water in arriving at a loading rate design factor.

In geographical regions where long periods of winter ice cover prevail, it is impossible to maintain aerobic conditions even with loading rates of less than 20 lb. BOD/acre/day. Studies of ponds in the Dakotas indicated that the allowable organic loading rate is dictated by the rate of reaeration during the critical season following ice break-up (Towne and Horning, 1960). Design loadings are generally in the range of 20 lb. BOD/acre/day in areas with long periods of ice cover. Loadings are therefore low, not for increasing treatment efficiency in terms of BOD reductions, but rather to prevent occurrence of nuisance conditions during certain periods of time. In some cases, essentially complete winter retention may serve as the basis for design rather than the organic loading rate. North Dakota, for example, requires provision for 150-day flow retention with discharge in the fall season when maximum stabilization has been accomplished.

In those geographical areas where winter ice coverage does not prevail, it has been shown that much higher loading rates than those common in colder areas are practical. (Neel, McDermott and Monday, 1961; Mills, 1961; Horning, et al., 1965; and Williford and Middlebrooks, 1967). Loading rates of up to 200 lb. BOD/acre/day were found to be feasible.

At Danang, Vietnam, U.S. Navy engineers reported that a loading of 220 lb. BOD/acre/day was satisfactorily treated while maintaining aerobic conditions near the surface of the pond. In a laboratory-scale, 24 square meter system, shallow cells readily stabilized domestic wastewater at loading rates of 600 lb. BOD/ acre/day without becoming anaerobic. The BOD reductions averaged 62% after a detention time of four days (Duttweiler and Burgh, 1969).

Canter (1969) and Canter, Englande and Mauldin (1969) reported on pond performance for loading rates up to 100 lb. BOD/acre/day in both bench-scale and field ponds in Colombia, South America. The average BOD removal was 93% with the algal cells removed from the effluent.

Canter and Englande (1970) reported on a survey of facultative pond design criteria used in 1968-69 in the United States. For analysis of the data, the 50 states were divided into three groups based on their general climatic conditions. The northern-most states have a cold climate with prolonged periods of ice cover on ponds during the winter. The central states generally have less severe winters and experience only short periods of pond ice cover. The southernmost states have mild climates and experience essentially no ice cover. The grouping of states as discussed herein is listed in Table 2.6. The following findings were observed:

(a) Organic Loading

As shown in Table 2.7, the recommended organic loading throughout the United States varies with latitude. The northern states have a mean design loading rate of 26 lb. BOD/acre/day, or an average population per acre of 124; central states have a mean loading rate of 33 lb. BOD/acre/day, or a mean population per acre of 189; and the southernmost states have a mean design loading of 44 lb. BOD/acre/day, or an average population per acre of 267. These results indicate that higher organic loadings are recommended as latitude location decreases, and this is directly related to corresponding milder climatic conditions.

(b) Detention Time

As shown in Table 2.7, the design detention time is also a function of latitude. Northern states have an average detention time of 117 days, whereas central and southern states have a mean of 82 and

TABLE 2.6: REGIONAL GROUPING OF STATES FOR QUESTIONNAIRE ANALYSIS

North	Central	South
Alaska	Colorado	Alabama
Connecticut	Delaware	Arizona
Idaho	Illinois	Arkansas
Maine	Indiana	California
Massachusetts	Iowa	Florida
Michigan	Kansas	Georgia
Minnesota	Kentucky	Hawaii
Montana	Maryland	Louisiana
New Hampshire	Missouri	Mississippi
New York	Nebraska	New Mexico
North Dakota	Nevada	North Carolina
Oregon	New Jersey	Oklahoma
Rhode Island	Ohio	South Carolina
South Dakota	Pennsylvania	Tennessee
Vermont	Utah	Texas
Washington	Virginia	
Wisconsin	West Virginia	
Wyoming		

TABLE 2.7: QUESTIONNAIRE RESULTS ON ORGANIC LOADING AND DETENTION TIME DATA

Variable	Value Given in Region		
	North	Central	South
Number of states	18	17	15
Organic loading (lb. BOD/acre/day)			
Mean	26	33	44
Range	16.7-40 (5)*	17.4-80(1)	30-50 (2)
Median	21	33	50
Loading (population/acre)			
Mean	124	189	267
Range	100-200(7)	100-400 (4)	175-300 (3)
Median	100	200	295
Detention time (days)			
Mean	117	82	31
Range	30-180 (11)	25-180 (5)	20-45 (9)
Median	125	65	31

*Number in parenthesis indicates the number of states for which no value was obtained.

31 days, respectively. Evaporation is considered in the design detention time in certain southwestern states (Nevada, Utah, and New Mexico). Calculations indicate that the increased detention time with increasing latitude results from a combination of decreased organic loading and the specification by some states that the entire winter flow be accommodated because of treatment difficulties experienced with pond ice cover.

(c) Liquid Depth

The average recommended liquid depth throughout the United States is 4 ft. Minimum depths are specified to discourage protuberant weeds, whereas values greater than maximum specific depths may cause inefficient pond operation. The minimum recommended depth in the nothernmost and central states is 2 ft., and in the southern states it is 3 ft. The maximum recommended depth is 6 ft. in the northern states, 15 ft. in the central and 5 ft. in the south.

(d) Freeboard

The average recommended freeboard between the liquid surface and the top of the surrounding levee is 3 ft. for the northernmost and central states and 2 ft. for the southernmost states. The minimum recommended freeboard in the northernmost states is 2 ft. and the maximum is 3 ft.; in the central states, 1.5 ft. and 3 ft.; and in the southernmost states, 1.5 ft. and 3 ft., respectively.

(e) Levees

Several considerations are involved in the design of pond levees, including top width, interior and exterior slopes, lining, and vegetation control. The maximum and minimum recommended levee top widths are 12 ft. and 8 ft., respectively, in the northernmost states. In the central and southernmost states the corresponding values are 10 ft. and 6 ft., respectively. Twenty-seven states recommend a levee top width of 8 ft.

The maximum recommended interior slope is 2.5 horizontal to 1 vertical for the northernmost states, 2:1 for the central states and 2:1 for the southernmost states. The corresponding minimum interior slopes are 6:1 for the northern states, 6:1 for the central states, and 4:1 for the southern states. An interior slope of 3:1 was either mentioned directly or in the recommended range in 36 states. The maximum recommended exterior slope is 2 horizontal to 1 vertical for all three groups of states. The corresponding minimum slopes are 3:1 for the northern states, 6:1 for the central states, and 4:1 for the southern states. An exterior slope of 3:1 was either mentioned directly or in the recommended range in 32 states.

An impervious lining is usually required if the levee seepage rate is excessive. Liner materials specified include riprap, clay, bentonite, diatomaceous earth, and asphalt. The sodium adsorption ratio of the wastewater has been found to have an influence on stabilization pond sealing (Matthew and Harms, 1969). As the ratio increases, the probability for natural sealing increases as a function of the type of soil.

Vegetation control for public health purposes consists of mowing, changing of water level, burning, and the use of herbicides.

(f) Geometric Configuration

Square and rectangular ponds are the most popular geometric configurations. Twelve states (Alaska, Montana, New York, Wisconsin, Colorado, Indiana, Iowa, Kansas, Kentucky, Ohio, Pennsylvania, and North Carolina) recommended that the pond length not exceed three times the pond width for a rectangular configuration. Circular, oval, and elliptical ponds were also mentioned as being acceptable. Missouri and Texas indicated that the pond shape could be in accordance with the terrain. In a study of pond shapes in Mississippi, rectangular facilities were found to enhance better liquid distribution and decrease short-circuiting over circular or irregular-chaped ponds (Shindala and Murphy, 1969).

(g) Number of Ponds

The majority of the states recommend the use of multiple ponds in order to provide operational and maintenance flexibility. Hydraulic arrangement of multiple ponds to permit either series or parallel operation is desirable. Wisconsin suggests that the area of the secondary pond in a series operations be only 25 to 33 percent as large as that for the primary pond. Single ponds are generally approved only for smaller installations.

Several recent studies have been directed toward the performance evaluation and design of two and three ponds in series (Englande, 1968; Mauldin, 1968; Moawad and El-Baroudi, 1969; Canter, 1969; Shindala and Freeman, 1970; and Aguirre and Gloyna, 1970).

(h) Pond Bottom

Most states recommend that the pond bottom be level, cleared of vegetation and impervious. The specified extent to which the pond bottom should be level varies from $\pm$ 3 in. to $\pm$ 12 in. Illinois recommends that pond bottoms be dished near the inlet in order to provide for solids deposition. Missouri recommends a depression around the inlet which has a depth equal to the inlet pipe diameter and a radius of 25 to 50 feet.

(i) Inlet

All states recommend a submerged discharge located far enough from any banks or levees to insure minimum interference with normal circulation. For small square or circular ponds, 32 states prefer a center discharge, whereas for larger rectangular lagoons, 17 states recommend discharge at the center one-third point most distant from the outlet. Multiple inlets are recommended by several states. Design features generally specified include horizontal discharge into a shallow, saucer-shaped depression for gravity flow, and vertical or horizontal discharge for forced flow. Submerged discharge onto a concrete pad is generally accepted. Gravity influent lines are required by 25 states to be located along the pond bottom with the top of pipe just below the average pond bottom elevation.

(j) Outlet

The preferred outlet location is generally at the far point from the inlet on the windward side to minimize short-circuiting. Some states specify that the location of outlet should be away from corners where accumulations of floating matter are heaviest. The most common design features incorporated include the ability to control liquid depth, drawoff near but below the liquid surface, design to permit complete pond drainage, and baffled overflow. These features are recommended by 33, 16, 11 and 9 states, respectively.

(k) Miscellaneous

Stock-tight fencing, appropriate signs, and influent flow measurements are required by 18, 14, and 16 states, respectively. Disinfection of the effluent by the addition of chlorine is required by several states. North Carolina and Ohio recommend an isolation distance from residences of 100 and 500 ft., respectively, whereas for Utah and Tennessee, 1000 ft. is specified. North Carolina and Tennessee recommend that dikes have rounded corners to minimize accumulation of floating materials.

2.9.2. Design Criteria for Developing Countries

Design approaches for waste stabilizations ponds in developing countries are presented by Callaway and Wagner (1966), and Gloyna (1971). Specific design recommendations for Colombia are presented by Canter (1969).

2.9.3. Empirical Design Equations

Empirically-derived design equations have been promulgated by some researchers. In establishing pond design criteria, Herman and Gloyna (1958) gave particular emphasis to the effect of temperature and its influence on the retention time in order to attain a given reduction of BOD. These criteria were developed after observing small laboratory ponds, pilot plants, and field installations. They found that the empirical relationship indicated in Equation 6, called the rational equation, has considerable merit for common types of wastewaters, particularly in the temperate and warmer areas. A minimum pond depth of 6 ft. is recommended.

$$V = 10.7 \times 10^{8}\ Q\ y\ \theta^{(35 - T)} \qquad \text{(Eq. 6)}$$

where:

V = waste stabilization pond volume (acre-ft.)

Q = wastewater flow (gal. per day)

y = influent 5-day, 20°C BOD (mg/l)

T = temperature (°C)

θ = temperature coefficient = 1.072

For more conservative designs, a θ value of 1.085 may be used in place of 1.072. It is important to note that this approach produces an allowable organic loading rate based on volume rather than surface area. In so doing, added emphasis is placed on temperature rather than solar radiation.

Aguirre and Gloyna (1970) developed an improved rational design equation, shown as Equation 7, for determining the required surface areas for facultative ponds.

$$A = 3.07 \times 10^{-3} Q' \, y_o 1.085^{(35 - T)} \, f \cdot f' \qquad \text{(Eq. 7)}$$

where:

A = surface area (acres)*

Q' = flow (million gallons per day)

y_o = influent ultimate BOD (mg/1)**

T = average temperature of coldest month (^oC)

f = algal toxicity or compensation factor, $f = 1$ for most domestic wastes

f' = sulfide correction, $f' = 1$ for SO_4 ion concentrations of less than 500 mg/1 for equivalent sulfur.

*This is based on a depth of 5 feet plus a sludge storage zone of one foot for all primary facultative waste stabilization ponds. The added foot need not be provided if an anaerobic pond preceeds the facultative waste stabilization pond. ***

**For domestic wastes containing unusually large amounts of settleable but biodegradable wastes it will be necessary to take special precautions to obtain a true equivalent ultimate BOD.

***The BOD5 removal efficiency can be expected to be about 90% as based on unfiltered influent samples and filtered effluent samples. The efficiency of removal based on unfiltered effluent samples can be expected to vary considerably but normally the values will range between 70% and 85%.

Marais and Shaw (1961) proposed an empirical design equation in which it is assumed that there is complete and instantaneous mixing and that the degradation of organic matter takes place according to a first-order reaction which is not temperature dependent. The Marais and Shaw equation was subsequently refined as shown in Equation 8:

$$L_p = \frac{600}{0.18\,d + 8} \qquad \text{(Eq. 8)}$$

where:

L_p = effluent BOD_5 (mg/1)

d = depth (m.)

Vincent developed an empirical design relationship for anaerobic ponds in tropical and subtropical regions (Gloyna, 1971). By assuming an influent and pond temperature of 20°C, Equation 9 was formulated:

$$L_p = \frac{y}{K_n\left(\frac{L_p}{y}\right)^n R + 1} \qquad \text{(Eq. 9)}$$

where:

L_p = pond and effluent BOD_5 (mg/1)

y = influent BOD_5 (mg/1)

R = detention time for completely mixed system (days)

K_n = design coefficient

n = exponent, for Zambia n = 4.8.

Thirumurthi and Nashashibi (1967) proposed a pond design approach based on reactor theory considerations usually applied to chemical engineering problems. They verified their theoretical design in laboratory experiments.

The stabilization of BOD in a pond has been described by a kinetic model (Gloyna, 1971) as follows:

$$L_p = \frac{y}{K_T R_T + 1} \qquad \text{(Eq. 10)}$$

where:

L_p = pond and effluent BOD_5 (mg/l)

y = influent BOD_5 (mg/l)

K_T = BOD stabilization rate at temperature T, T in ^{o}C, and K_T in per day

R_T = detention time at temperature T (days)

The assumptions for the kinetic model are: 1) the influent BOD is stabilized by facultative organisms, 2) there is complete mixing, and 3) stabilization is by a first-order reaction.

Another empirical approach formulating organic loading has been obtained from performance and loading relationships (Herman and Gloyna, August, 1958). Data compiled from 18 aquarium models operated under both indoor and outdoor temperature and lighting conditions yielded a straight line relationship as indicated in Equation 11. Pond failures at excessive loadings provide a practical limit to the applicability of this equation.

$$P = 100 - 0.05\ (L) \qquad \text{(Eq. 11)}$$

where:

P = percent decrease in BOD_5 in laboratory ponds

L = loading rate (lb. BOD_5/acre/day)

Englande (1968) developed Equation 12 for centrifuged samples based on both laboratory and field tests. Equation 12 is similar to Equation 11.

$$P = 93 - 0.02\ (L) \qquad \text{(Eq. 12)}$$

McGarry and Pascod (1970) have shown that area BOD removal can be estimated through knowledge of area BOD loading:

$$L_r = 9.23 + 0.725\ y \qquad \text{(Eq. 13)}$$

where:

L_r = areal BOD removal (lb./acre/day)

y = influent BOD_5 (mg/l)

Equation 13 applies to tropical and temperate zones and has a standard error of estimate equal to 14.9 lb./acre/day.

Siddiqi and Handa (1971) developed a design relationship for facultative ponds based on operational experiences in India. The performance efficiency can be described by Equation 14:

$$P = \frac{100}{1 + 0.188\ L_f^{0.48}} \qquad \text{(Eq. 14)}$$

where:

P = BOD removal efficiency (%)

L_f = load factor which is ratio of BOD loading (lb./acre/day) to oxygen production by algae (lb./acre/day); Eq. 14 applies for L_f values between 0.44 and 8.0.

Gloyna (1968) has suggested that consideration be given to the contribution of the bottom sludge layer to the total organic loading imposed on a pond. In the sludge layer anaerobic degradation occurs, resulting in gas evolution and release of fermentation products; these products can exert a considerable BOD and perhaps should be considered in design. As a rule of thumb, Gloyna suggests using a weighted average of soluble BOD_5 of the influent and the ultimate BOD of settleable solids for the value of influent BOD_5. A further refinement of this approximation is shown by Equation 15.

$$Y_{up} = \frac{Y_{ui}}{Kt + 1} (f_p + c_p f_s) \qquad \text{(Eq. 15)}$$

where:

Y_{up} = ultimate pond BOD

Y_{ui} = ultimate influent BOD

t = retention for completely mixed system

f_p = fraction of influent BOD to pond liquid

f_s = fraction of influent BOD to sludge layer

c_p = fraction of fermentation products from sludge layers entering pond liquid

K = degradation rate

Empirical design approaches for high-rate aerobic ponds are presented by Rich (1963), Jayangoudar, et al. (1970), and Gloyna (1971).

2.10. Pond Effluent Quality

Serious objections to pond use are usually based on potential nuisance and operational problems and the effect of pond effluents on downstream water quality (Barsom, 1973). Undesirable fly and mosquito breeding may occur in ponds which have uncontrolled weed growths. Odors may result from ponds which have become overloaded, or are experiencing the spring break-up of ice cover. Prolific algal growths can create algal mats and scum layers on pond surfaces. The presence of surface active materials in sufficient concentrations can cause froth and foam both on the pond surface and in the effluent. Effluent BOD and suspended solids may exceed discharge standards (Dougall, 1973).

Concern regarding pond effluent quality has centered around the possible presence of pathogenic organisms and the demand exerted on the oxygen resources of the receiving stream due to algae respiration and algal cell decay. The BOD in the pond influent is not completely removed; it is in part transferred into another form (algal cells). In addition, algae have been found to affect BOD test results (Varma, Horn, and Reid, 1963). There are other effects that algae can exert on stream quality. The presence of algae may create limitations on downstream water uses such as recreation. Downstream water treatment plant costs may also increase. Decaying algae can create nuisance odors in the receiving body of water. Some algae are capable of releasing metabolic by-products which are toxic to bacteria and other life forms.

Several facets of design and operation can be utilized in order to optimize pond effluent quality. These include: 1) prevention of hydraulic short-circuiting, 2) outlet design to permit effluent withdrawal from various depths, 3) chlorination, 4) use of tertiary treatment, and 5) use of biological approaches for algae control.

The hydraulic arrangement of ponds to minimize short-circuiting of flow is necessary in order to insure provision of the design detention time. The use of multiple ponds and flow-control levees within ponds are examples of design features which can be used to minimize short-circuiting (Oswald, 1973).

Since the major concern regarding pond effluent quality is related to the presence of algal cells, one approach to improving quality is to minimize the algal cell content in the effluent. One method of accomplishing this is to provide an outlet design which will permit effluent withdrawal from various depths. Since the greatest algal concentrations occur within two feet of the water surface, effluent withdrawal at greater depths may be desirable.

Effluent chlorination serves to reduce bacterial numbers as well as algal cells; however, the release of cell products may be undesirable (Missouri Basin, 1971).

Tertiary treatment of pond effluents could be provided if high effluent quality is necessary. This type of treatment is usually aimed at removing algal cells (Stander, et al., 1970). Physical separation can be accomplished through the use of micro-strainers or rock or sand filtration (Missouri Basin, 1971, Kothandaraman and Evans, 1972; Lewis and Smith, 1973; and Marshall and Middlebrooks, 1974). Chemical precipitation of algal cells through the addition of alum, lime, ferric salts, or cationic polymers has been reported in the Missouri Basin report (1971) and by Kothandaraman and Evans (1972), Lewis and Smith (1973), and Folkman and Wachs (1973). The ultimate disposal of the harvested algae may involve uses such as animal feed supplements, soil conditioners, and gas production (Kothandaraman and Evans, 1972).

Biological approaches for removing algal cells and improving pond system effluent qualities include the use of maturation ponds (Marais, 1966; Gloyna, 1971; and Potten, 1972); or algal cell predators such as Daphnia (Dinges, 1973), water hyacinths (Miner, et al., 1972), and fish (Lewis and Smith, 1973; and Spear, 1974).

2.11. Operation and Maintenance

In principle, the operation of a waste stabilization pond is simple; however, if inadequate operation and maintenance occurs the advantages gained through the treatment of wastewaters may be lost (Gloyna, 1968). Regular inspections must be made of the levees, surface growths, and general pond performance. Ponds are usually equipped with control devices that regulate influent rates, effluent releases, and liquid levels. These devices must be inspected regularly. Stopgates and valves will rust and deteriorate unless properly maintained.

Nuisance midges and mosquitoes have been found to breed in ponds in large numbers. With particular reference to mosquitoes, it is necessary to exercise stringent maintenance procedures. It is undesirable to allow sludge deposits to develop on the levees. Weeds and grasses provide shelter for mosquito larvae. A minimum water depth of about three feet will prevent the emergence of most aquatic plants. The grasses and weeds at the edge can be controlled by mowing. In the United States portable flame throwers or burners have proven useful in burning the small weeds and grasses along the pond edge. The use of herbicides and soil sterilants at the edge of the water has also proven beneficial (Canter and Englande, 1970). The introduction of top-feeding water minnows, Gambusiae, may be worthwhile in secondary or tertiary ponds (Sholdt, et al., 1972).

Almost every pond will periodically have a scum or floating algal-mat problem. This scum will be blown toward a corner of the pond. If permitted to accumulate, serious odor and insect problems will arise. After scum accumulation occurs, the only solution is to agitate the water sufficiently so that the material will again settle to the bottom or become dispersed. Several facilities in the United States utilize gasoline-powered paddle wheels mounted on a raft. Water jets have proven equally successful. The location of the surface aerator in critical corners could also help alleviate the problem (Canter and Englande, 1970).

2.12. Cost Considerations

Land cost is the major item in the initial investment in a pond system. Although the costs for each pond system have to be considered separately, some general costs information can be presented. In 1966, Wright indicated that the median first cost of a waste stabilization pond was $12 to $20/capita. This was estimated to be about 25 to 50% of the first cost of an equivalent conventional biological treatment plant. Wright also indicated that the operating and maintenance costs for a pond were about $0.20 to $1.00/person/year. This figure represents about 25% of the cost of operating an equivalent conventional plant. Gloyna (1971) presented detailed information on pond costs in the United States and around the world.

Chapter 3

EXPERIMENTAL PROGRAM AND RESULTS

A field pond study was conducted for a period of approximately five (5) years from February, 1969, through December, 1973. There were four major operational phases, each having a specific purpose and each being separated from the others by time. The purposes were as follows:

(1) Phase I: To determine whether, for a given wastewater loading, a four- or six-foot liquid depth offered the better treatment, and to establish a base of reference data to which the data from the subsequent three operational phases could be compared. This phase was conducted from February, 1969, to June, 1971.

(2) Phase II: To determine the optimum wastewater loading for a single-celled pond. This phase was carried out from June, 1971, to August, 1972.

(3) Phase III: To determine whether, for a given wastewater loading, a single-celled or a two-celled pond system offered more advantages. This phase was accomplished from August, 1972, to July, 1973.

(4) Phase IV: To determine if the addition of a small anaerobic pond at the beginning of a two-pond series system would reduce wastewater short-circuiting and allow a greater quantity of solids settling, thereby permitting a substantial increase in

bacterial and BOD removals as compared to systems where only facultative ponds were involved. This phase was the focus from July through December, 1973.

3.1. Description of Operational Phases

In Phase I (February, 1969, to June, 1971), two pilot stabilization ponds were used. Each of the two ponds had length to width ratios of 2:1 and embankments with horizontal to vertical slopes of 3:1. The berms of the ponds were eight feet above the pond bottoms, and each of the two ponds had a 0.5 acre surface area when operated at a liquid depth of five feet. Wastewater entered the ponds through vertical risers which extended six inches above the bottom of each pond, and were located one-third of the length of the ponds from the influent end. Approximately six feet from the opposite end, the effluent was discharged into a standpipe. Baffles around each standpipe excluded floating material in the top three inches of each pond.

Data collection commenced during February, 1969, with the two stabilization ponds being operated independently and having different depths (Figure 3.1). The pond designated as "Pond 1" was operated at a six-foot depth, and the pond designated as "Pond 2" was operated at a four-foot depth. The wastewater loadings were held relatively constant at about 200 lbs. BOD/acre/day for Pond 1 and at 250 lbs. BOD/acre/day for Pond 2 for the duration of Phase I.

In April, 1971, the six-foot pond was drained and structurally modified so that it would maintain a depth of four feet. This pond, Pond 1, was placed back in operation in June, 1971, marking the beginning of Phase II (June, 1971, to August, 1972). During Phase II independent operation of the ponds was continued, however, both ponds had four-foot depths (Figure 3.1.). Phase II was accomplished using the percentage removal of BOD within the ponds as the criteria for failure. The BOD loading was increased to Pond 1 over the Phase I loading by increasing the influent flow until failure occurred. The BOD loading to Pond 2 was correspondingly decreased by decreasing the influent flow.

During Phase III (August, 1972, to July, 1973), Ponds 1 and 2 were operated in series as shown in Figure 3.2. Series operation was accomplished by constructing a channel between the two ponds which was perpendicular to and midway along the pond lengths, and by capping the standpipe in Pond 2, thus raising the liquid depth of Pond 2 to five feet. The first pond (Pond 2) in the two-pond system ranged from 235-600 lbs BOD/acre/day, the system loading was from 135-337.

The construction of a third pond was accomplished in the spring of 1973 so that Phase IV (July, 1973, through December, 1973) of the project could be conducted. The third pond was an anaerobic pond having a length to width ratio of 3:1. The embankments of the third pond had horizontal to vertical slopes of 1:1. The berms were twelve feet above the pond bottom and the surface area was 1,716 square feet (0.039 acres) when operated at a six-foot depth.

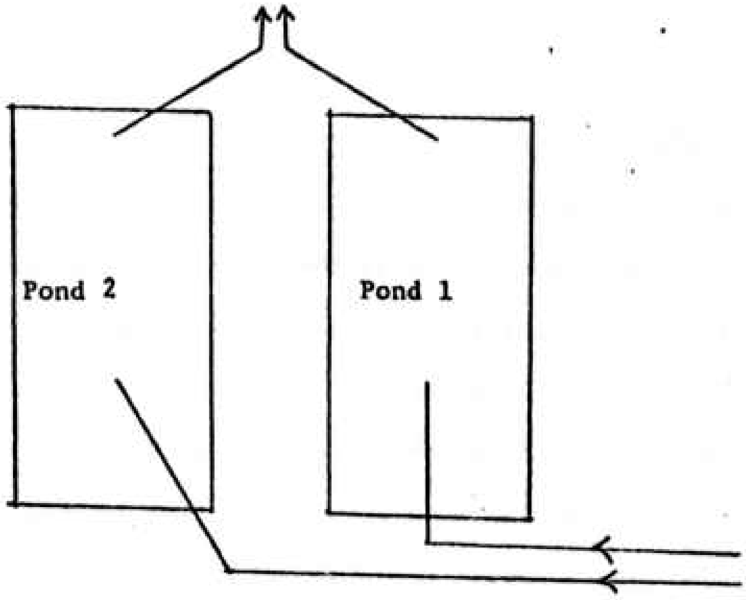

Figure 3.1: Pond System Operational Arrangement for Phases I and II.

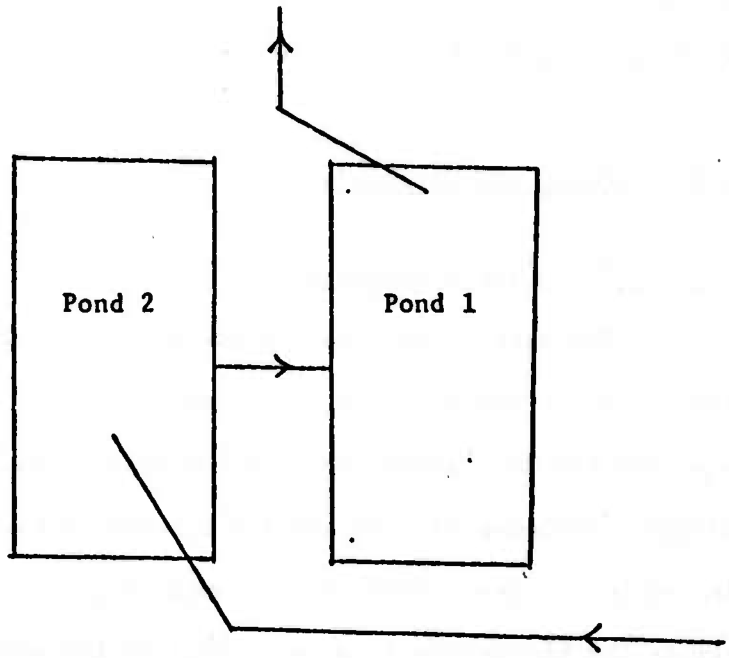

Figure 3.2: Pond System Operational Arrangement for Phase III.

Wastewater entered this pond by means of a twelve-inch concrete pipe placed horizontal to and three feet above the pond bottom. Wastewater exited the pond at the opposite end by means of a "T" attached to the end of a twelve-inch concrete pipe. Flow into and out of the pond was by gravity. The wastewater flow was from this small anaerobic pond, which was designated "Pond 3", to Pond 2 and then to Pond 1 as shown in Figure 3.3. The overall loading on this three-pond system ranged from 105 and 242 lbs. BOD/acre/day. The BOD loadings on the system had to be kept low due to the smallness of the anaerobic pond. This small pond had an average theoretical detention time of 0.43 days with BOD loading rates ranging between 4,900 and 11,200 lbs. BOD/acre/day.

3.2. Methods and Materials

3.2.1. Flow Characteristics

The pilot stabilization ponds were located on Miraflores Island. The Island is bracketed by Fort Clayton and the Rio Grande River on one side and the Panama Canal on the other side. Wastewater from Fort Clayton, Cardenas Village and the Curundu Elementary School was collected in a sewer system which flowed to a pump station directly across the Rio Grande from the stabilization ponds. The flow was pumped beneath the Rio Grande, across Miraflores Island and into the Panama Canal via a force main.

The pilot ponds were constructed next to the force main. A valve was placed in the force main so that the flow to the pilot ponds

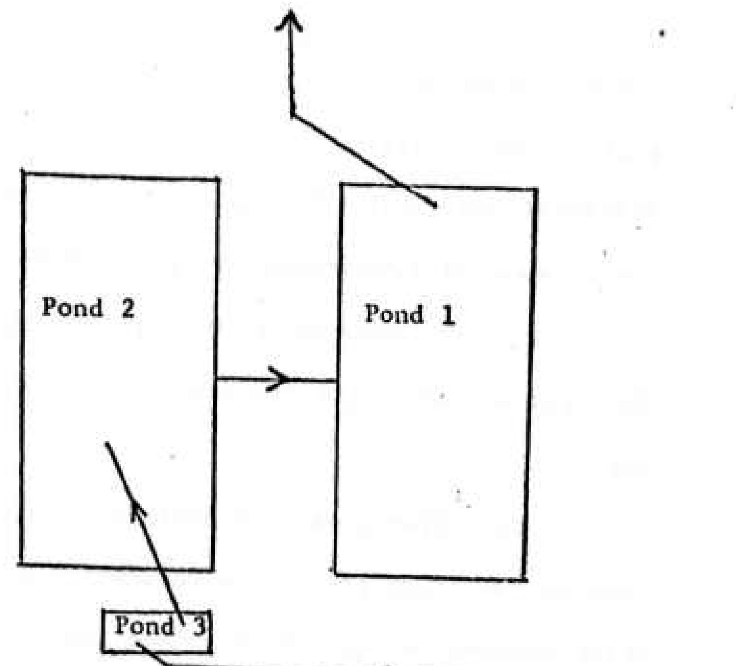

Figure 3.3: Pond System Operational Arrangement for Phase IV.

could be regulated. Regulation of the flow was difficult. The pump station had a stilling well and flow was pumped intermittently at different intervals. During the peak flows on a typical day the surges came at five minute intervals and lasted three minutes. As a result of large amounts of infiltration and the intermittent pumping the flow was impossible to regulate within more than 50 lbs. BOD/acre/day.

Upon diversion of a portion of the wastewater in the force main to the pilot ponds, the wastewater entered a small stilling well which allowed an equal division of the wastewater when desired. From the small stilling well the wastewater entered the ponds as described in the previous section. The final pond system effluent flowed into the Panama Canal.

3.2.2. Wastewater Characteristics

The wastewater collected in the Fort Clayton sewer system represented the wastewaters of approximately 7,000 people. Six thousand persons lived in family housing while 1,000 people lived in barracks and ate in military dining facilities. Although another 500 people worked within the sewered area, it was assumed that a like number of people worked outside the area as came to the area on a daily basis. The 900 children who attended the elementary school all lived within the Fort Clayton area, so they were included in the 6,000 persons living in family housing.

The wastewater from Fort Clayton had an average flow of 1.1 million gallons per day. The wastewater was predominantly domestic in nature. The Fort Clayton area has no major industrial-type activities and no significant major medical facilities. There were, however, several military motor pools and automobile repair garages situated among the many family housing units, barracks buildings, and administration facilities.

The Fort Clayton area had separate sanitary and storm sewer collection systems. It is known, however, that sufficient quantities of runoff infiltrated the sanitary sewer system to significantly effect the characteristics of the collected wastewater. It is realistic to anticipate that similar infiltration will occur at most Army camps or bases located in tropical areas.

Not only were there large amounts of infiltration throughout the project, but it became increasingly worse as the project progressed. To illustrate the increasing infiltrations, the following figures are given to show the weakening of the wastewater with time:

Time Period	Average BOD (mg/l)
February, 1969 - December, 1972	179
January, 1972 - September, 1972	167
October, 1972 - June, 1973	145
July, 1973 - December, 1973	118

Besides the quantity of infiltration, there are other characteristics which may vary from installation to installation. The wastewater received by the pilot ponds of this project had passed through pumps, a comminuter and grit chamber which may or may not be present in other Army installation sewer systems. The indigenous pathogens vary greatly from tropical area to tropical area. The effect of stabilization ponds on pathogens which are not present in the Canal Zone can only be estimated. The quantities of bacteriological data recorded and analyzed during this project should allow reasonable predictions of removal efficiencies of pathogens not indigenous to the Canal Zone. Also, the climatic conditions would differ from area to area.

3.2.3. Parameters

The following parameters were analyzed and recorded during this project:

(a) Hydraulic Loading

(b) BOD Loading

(c) Detention Time

(d) Depth Profiles (Temperature, DO, & pH)

(e) Nitrogen (NH_3, Nitrate, Nitrite, & Organic Nitrogen)

(f) COD

(g) Solids (TS, SS, Volatile, & Settleable)

(h) Acidity & Alkalinity

(i) Phosphates (Total, Ortho-, & Poly-)

(j) Algae (Concentration & Profiles)

(k) Meteorological Data (Temperature, Precipitation, Relative Humidity, Vertical Eppley Radiation, Wind Direction & Speed & Evaporation)

(l) Bacteriological Data (Total Colony Counts*, Quantitative and Qualitative Bacteria Counts, & Fecal, *Escherichia coli*, & Total Coliform Counts).

*Incubated at 25°C and 37°C.

3.2.4. Discussion of Parameters and Sampling Procedures

(a) Wastewater flow: The flow entering the pilot ponds varied greatly within a given twenty-four hour period, with peak flows occurring just after meal times and little or no flows between midnight and six a.m. When daily or weekly flows collected by the sewer system are compared to flows occurring on another day or for another week, the flow variations are small with exceptions occurring as a result of infiltration after periods of heavy rainfall.

Monitoring the wastewater flow into the pilot pond systems was accomplished daily for the duration of the project, utilizing a 9-inch throat Parshall flume and a Stevens Total Flow Meter and Water Level Recorder. Both the total flow meter and the water level recorder were required because of the intermittent hydraulic loading of the pond systems. The influent and effluent of the small anaerobic pond, Pond 3, were assumed to be the same. It was felt that the size of this small pond and the volume of wastewater transiting it each day justified this assumption. The flow between the two larger ponds, Ponds 2 and 1, was recorded using a 9-inch throat Parshall flume and a Stevens Total Flow Meter. The flow level recorder was not required at this point since this flow, unlike the system influent, was steady. The final effluent flows of the pilot pond systems entered 3-inch throat Parshall flumes and were measured by Stevens Flow Level Meters.

(b) Biochemical Oxygen Demand: The 5-day, 20°C BOD was determined according to procedures set forth in the twelfth edition of

Standard Methods. The azide modification of the iodometric method for BOD dissolved oxygen determination was utilized. An average of seven samples per month from each sampling point were analyzed for their BOD content for the duration of the project.

Samples for the determination of BOD concentrations in the pilot pond systems influents were initially collected utilizing a Serco Automatic Sampler. This sampler is designed to take twenty-four samples, one each hour, for a given twenty-four hour period, thereby producing a sample which resembles a twenty-four hour composite sample. However, because of the intermittent flow to the pilot ponds no more than seven of these hourly samples were collected on any given day.

A study was conducted to determine how representative grab samples were of the twenty-four hour composite. Six twenty-four hour composite studies were conducted on the system influent over a three month period. The samples were composited on an hourly and on a daily basis. Also, grab samples were analyzed to determine if they were representative of the hourly samples of the hour in which they were taken. It was also discovered that grab samples taken between 0800 and 0900 hours were representative of the twenty-four hour composite samples. In the six surveys conducted, the average difference in BOD concentration found in the grab samples taken between 0800 and 0900 hours and in the composite samples was less than four percent.

As a result of the composite studies, and considering the few hourly grab samples collected by the automatic sampler, the problem of refrigerating the collected samples, and the general physical condition of the sampler, the use of the Serco Automatic Sampler was discontinued in January, 1972. From January, 1972, until the end of the project the system influent samples were grab samples taken between 0800 and 0900 hours.

Samples for the determination of BOD concentrations in the effluent of the small anaerobic pond, Pond 3, were grab samples collected between 0800 and 0900 hours. The wastewater samples collected from the channel between the two larger ponds, Ponds 2 and 1, and from the final effluent channels of the pond systems were collected using Stevens Composite Samplers. The sample taken between the two larger ponds was refrigerated by placing the composite sampler in an insulated box into which refreezable "Ice-Pak's" had been placed. The final effluent samplers were kept inside refrigerators.

As has been shown, many parameters were monitored. Although these many parameters have been analyzed in this report to determine their relationships and significance, most played a very small role in the planning and controlling of the research. For the most part, the BOD parameter was used to plan and control the quantity of wastewater, and therefore, the wastewater loadings utilized throughout the research project. The BOD was chosen as the regulating parameter for several reasons. The majority of other research reported in the literature uses BOD as the controlling parameter, and even when BOD is not the controlling parameter, it is almost always recorded. Thus, there is a large amount of information on BOD loadings and removals for different types of pond systems. Also, BOD is a universally accepted parameter for designing and monitoring wastewater treatment facilities. Last but not least, the manpower required to analyze and evaluate all the parameters so that they all could be used to control and monitor the wastewater which the ponds were receiving was neither available nor practical.

The BOD values shown in this report were all determined without filtering or centrifuging the collected samples. The BOD values were determined on several occassions after the samples had been centrifuged. The centrifuged samples always resulted in a BOD removal of greater than 90 percent. It was felt that centrifuging removed a significant number of solids as well as algae. Also, it was felt that even if solids were not removed that the algae discharged into a receiving body of water may represent a significant oxygen demand on the receiving waters. Therefore, it is felt that this is the most representative means by which to present the BOD data.

(c) Depth Profiles (Temperature, DO, & pH): Concentrations of dissolved oxygen and temperature at preselected vertical intervals in the two larger stabilization ponds were determined using a Yellow Springs Instruments Company, Model 51 Oxygen Meter. This instrument was equipped with a probe having a 10-foot lead. The cathode of the probe was a gold ring imbedded in a lucite block, and the anode was a silver coil recessed in the central wall. The electrolyte around the anode coil was a half-saturated solution of potassium chloride. Field calibration of the probe was performed against the known concentration of oxygen in ambient air. Laboratory calibration was performed periodically against samples of known dissolved oxygen concentration. This was determined by the Winkler method for dissolved oxygen using the azide modification of the iodometric method. The probe was equipped with a thermister for temperature determinations.

In December, 1969, the portable Oxygen Meter utilized to determine dissolved oxygen, in situ, at various depths within the ponds became inoperable and was returned to the manufacturer for repairs. It was not received until May, 1971. During this interval, depth samples were obtained using a modified Van Doren sampler, and dissolved oxygen was determined in the laboratory by the azide modification of the Winkler method. Due to inaccuracies inherent to this method, values below one mg/l could not be reliably determined, and are simply reported as being less than one mg/l.

The pH was determined using either a Photovolt Model 126 A pH meter or an Analytical Measurements Pocket pH meter. The meters were periodically calibrated against two of the standard buffers of pH 4.0, 7.0 and 9.6. Most determinations of pH values were made, in situ, at different depths within the stabilization ponds. This was accomplished by using the Analytical Measurements pH meter which had probes mounted in a one-piece unit which was affixed to a 25-foot lead. Otherwise, pH determinations were made upon samples retrieved from the desired depth through the use of a modified Van Doren sampler.

The profiles were conducted at the centers of the two larger ponds. No profiles were taken in the small anaerobic pond. Access to the center of the ponds was accomplished by the construction of catwalks from the pond embankments to their centers.

Temperature, D.O. and pH profiles were conducted an average of four times per month between February, 1969, and September, 1969. From October, 1969, through October, 1971, profiles were on a monthly basis. No profile data was collected between November, 1971, and February, 1972, because of the bad state of repair of the catwalks and because of malfunctions in both of the pH meters and in the oxygen meter. In February and March of 1972, temperature and D.O. profiles were conducted. Due to additional problems with the oxygen meter and a shortage of manpower, no more profiles were made until February, 1973, when a new oxygen meter was acquired. Temperature and D.O. profiles were conducted monthly for the remainder of the project. Although no pH profiles were conducted after October, 1971, pH data is available from samples taken from the different sampling points discussed previously.

Representative values for dissolved oxygen and temperature within the two facultative ponds are shown in Tables 3.1 and 3.2. Table 3.1 represents a wet season profile while Table 3.2 represents a dry season profile.

<u>(d) Nitrogen (NH_3, Nitrate, Nitrite, Organic)</u>: All nitrogen determinations were made in accordance with procedures in the twelfth edition of <u>Standard Methods</u>. The direct Nesslerization method was used for ammonia nitrogen, and organic nitrogen was determined by the Kjeldahl method after removal of the free ammonia. Nitrite nitrogen determinations were made by the diazotization method, and if analysis could not be performed immediately, the sample was temporarily

TABLE 3.1: DISSOLVED OXYGEN AND TEMPERATURE PROFILE, WET SEASON (October)

Depth, ft.	Time	D.O., mg/l	Temp., °C
0.0	0930	2.8	28.2
1.0	"	0.9	27.0
2.0	"	0.9	26.6
3.0	"	0.7	26.7
4.0	"	0.6	26.5
0.0	1100	2.2	31.3
1.0	"	0.8	27.4
2.0	"	0.8	26.8
3.0	"	0.8	26.7
4.0	"	0.7	26.6
0.0	1320	17.9	34.0
1.0	"	1.0	28.6
2.0	"	0.9	27.0
3.0	"	0.8	26.8
4.0	"	0.8	26.6
0.0	1500	19.2	36.4
1.0	"	1.4	28.8
2.0	"	0.9	27.2
3.0	"	0.9	26.9
4.0	"	0.8	26.7

TABLE 3.2: DISSOLVED OXYGEN AND TEMPERATURE PROFILE, DRY SEASON (April)

Depth, ft.	Location	Time	D.O., mg/l	T.,°C	pH
0.0	Pond Center	0900	0.8	28.4	6.9
1.0	"	"	0.7	27.8	6.8
2.0	"	"	0.7	27.1	6.7
3.0	"	"	0.7	26.8	6.7
4.0	"	"	0.6	26.8	6.7
0.0	"	1050	0.9	29.9	7.0
1.0	"	"	0.8	28.4	6.7
2.0	"	"	0.7	27.3	6.8
3.0	"	"	0.7	26.9	6.7
4.0	"	"	0.7	26.8	6.6
0.0	"	1310	8.4	34.4	7.6
1.0	"	"	0.8	29.1	6.9
2.0	"	"	0.7	27.8	6.7
3.0	"	"	0.7	27.1	6.7
4.0	"	"	0.6	27.0	6.6
0.0	"	1500	10.8	34.9	7.9
1.0	"	"	0.9	29.4	6.9
2.0	"	"	0.6	27.9	6.6
3.0	"	"	0.6	27.1	6.6
4.0	"	"	0.6	27.1	6.6

preserved with sulfuric acid. The brucine method was used for the determination of nitrates.

Samples for nitrogen were acquired in the same manner as for BOD. Sampling for organic nitrogen and ammonia was begun in February, 1969, and continued through April, 1971, with an analysis frequency of two to four times per month. In May, 1971, organic nitrogen and ammonia analyses were reduced to once per month and this procedure continued for the project duration. It was felt that a substantial data base for these two parameters had been established, thus warranting the reduced frequency of analysis.

The frequency of analysis for nitrites was the same as for organic nitrogen and ammonia until May, 1972, at which time nitrite analysis was discontinued. It was felt that all the nitrite data which could be useful had already been obtained.

Nitrate analysis was accomplished two to four times per month between February, 1969, and January, 1972. From January, 1972, through December, 1973, nitrates were analyzed weekly. It was felt that of the four nitrogen parameters this parameter offered the most meaningful data, so its frequency of analysis was increased while analyses for the other forms were either decreased or eliminated.

(e) Chemical Oxygen Demand: The COD determinations were made by the dichromate reflux method as described in the twelfth edition of Standard Methods. Samples were homogenized using a blender to permit representative sampling. Any time there was a delay between sampling and analysis, the samples were preserved by acidification with sulfuric acid.

Sampling was accomplished at the same points and by the same methods as were used for BOD. Sampling was begun in May, 1970, and from May, 1970, through December, 1971, the frequency of sampling was one to three samples per month. From January, 1972, through December, 1973, samples for COD were analyzed weekly. The increased number of samples analyzed for COD was a result of better management of manpower.

(f) Solids (TS, TSS, TVS, Settleable): Total solids (TS), total volatile solids (TVS), total suspended solids (TSS) and settleable solids (SS) were all analyzed according to the twelfth edition of Standard Methods. Total solids were determined by evaporation. The total solids were then placed in a muffle furnace containing a temperature of 600°C so that the total volatile solids might be determined. Total suspended solids were determined using Grade 934 AH Reeve-Angel glass fiber filters. The pore size of these filters was unknown and may have been too large since the total suspended solids values were lower than anticipated. Finally, the Imhoff Cone was used to measure the amount of settleable solids.

The sampling points and collection procedures were the same for total solids as previously described for BOD. From February, 1969, through April, 1970, samples for TS were analyzed on all working days. From May, 1970, through December, 1971, and from February, 1973, through December, 1973, monthly analyses for TS were made. Data for TS was not collected between January, 1972, and January, 1973. The absence of data during this period was a result of a manpower shortage and destruction of some elements in the muffle furnace.

Total volatile solids (TVS) samples were collected in the same manner as the TS samples and were analyzed with the same frequency until December, 1971, at which time the analyses were discontinued. As a result of the work load being placed on project personnel it was felt that the beneficial data obtained from these analyses did not justify their continuation. Also, it was felt that analysis for TSS was more important.

Total suspended solids (TSS) samples were collected in the same manner as TS samples. The samples were analyzed each working day from July, 1972, through October, 1973. The technicians were not able to finish analyzing the TSS samples because of other tasks which took priority. The samples for the last two months of the project became too old to be analyzed and had to be discarded.

Settleable solids (SS) determinations were made only on the influent and effluent of Pond 3, the small anaerobic pond. These analyses were made to determine the efficiency of this pond in removing settleable solids. The determinations were conducted each workday for which Pond 3 was in operation (July, 1973, through December, 1973).

(g) Alkalinity and Acidity: Accepted methods of wastewater analysis for alkalinity and acidity were followed. Alkalinity was determined by successive titration to the methyl orange endpoint using sulfuric acid. Acidity was determined by the potentiometric titration method.

Samples for alkalinity and acidity were collected in a like manner to BOD samples. From February, 1969, through April, 1970, samples for alkalinity and acidity were collected weekly. From May, 1970, through the end of the project alkalinity samples were collected monthly. Samples for acidity were collected monthly from May, 1970, through December, 1971, at which time acidity sampling was discontinued. An acidity data base had been established, and it was felt that the analysis was no longer justificable due to other resource requirements.

(h) Phosphate (Total, Ortho-, Poly-): Determinations for phosphate were accomplished in accordance with the twelfth edition of Standard Methods. The aminonaphtholsulfonic acid method was used for orthophosphates.

Samples were collected in the same manner as for BOD sampling. Analyses for orthophosphates were conducted semimonthly between August, 1969, and February, 1972. Beginning in March, 1972, the analyses for orthophosphates were increased to a weekly basis as a result of the discontinuance of analyses for total and poly phosphates. Also, it was felt that the orthophosphate analyses were important enough to justify the increase.

Total phosphate analyses were conducted weekly from March, 1969, through June, 1969. From August, 1969 through April, 1971, the analyses were conducted semimonthly. Samples were not analyzed for total phosphates after April, 1971. Total phosphates were recorded weekly for the first four months of analyses because it was desired to build a base of data.

Polyphosphates were recorded semimonthly from August, 1969, through April, 1970, at which time they were discontinued. The analyses were discontinued due to resource priorities.

(i) Algae: Procedures for sampling, identification, and counting of algae were according to Standard Methods. A modified Van Doren sampler was used for retrieval of samples from desired depths within the stabilization ponds. Identification was performed upon fresh samples, and direct counts were made upon samples to which formalin had been added.

Counting and identifying of algae in samples began in October, 1969. The samples were collected from varying depths at the centers of each of the two large ponds (Ponds 1 & 2). Usually four algae profiles for each pond were conducted on a given sampling day. Two profiles were done in the morning and two were conducted in the afternoon. See Table 3.3 for typical profiles taken during the dry and wet seasons.

Sampling for algae was accomplished weekly from October, 1969, through May, 1970; semimonthly from June, 1970, through September, 1971; and monthly from October, 1972, through October, 1973. The reductions in the frequency of algae profiles was a direct result of resource priorities.

There are three time periods between October, 1969, and December, 1973, for which no algal data was collected. The data for April, 1971, through September, 1971, was misplaced. The hazardous conditions of the catwalks resulted in no algal counts from October, 1971, through January, 1972. Finally, algae were not identified and counted for the final two months of the project because of resource priorities.

TABLE 3.3: ALGAE CONCENTRATION, WET SEASON (OCTOBER)

Month	Time	Chlamydomonas Surface	Chlamydomonas 1.0 ft	Chlorella Surface	Chlorella 1.0 ft	Euglena Surface	Euglena 1.0 ft	Total* Surface	Total* 1.0 ft
(1970)									
October	0930	3.9	5.4	0.5	2.2	102.9	2.8	107.3	10.3
	1100	1.0	2.3	1.4	1.6	88.5	0.8	11.0	4.6
	1320	5.3	1.5	7.4	3.2	15.8	0.8	28.5	5.5
	1500	4.3	0.5	7.9	1.5	38.0	0.8	50.4	2.8
(1971)									
March	0920	14.9	19.9	4.6	0.4	0.5	0.9	20.1	21.2
	1100	22.1	15.8	1.3	4.7	1.0	0.3	24.9	20.8
	1330	3.2	5.1	2.2	3.5	1.8	0.5	7.3	9.1
	1500	3.7	3.2	3.4	2.0	1.6	0.5	8.7	5.8

*Includes other algae than those specifically listed in this table.

(j) Meteorology: Meteorological measurements were recorded for the duration of the project. The parameters measured included ambient air temperature, relative humidity, precipitation, vertical Eppley radiation, wind speed and direction, and evaporation. The equipment utilized for each parameter was: A Hygrothermograph for relative humidity and ambient air temperature, an evaporation pan for evaporation, a weighing-type recording 8 in. raingage for precipitation, a Pyreheliometer for vertical Eppley radiation and an An/GMQ-11 wind measuring system for wind speed and direction. All measurements, except evaporation which was daily, were recorded hourly. The equipment was furnished and maintained by the U. S. Army meteorological Team (ROT & ESpt), Canal Zone.

The meteorological data was relatively constant for the five years of the project. For this reason a five-year monthly summation of the meteorological data is presented in Tables 3.4-3.9. This data can be referred to when reviewing any of the different phases of the stabilization pond research. For a breakdown of the meteorological data on a yearly basis see Appendix I.

(k) Bacteria: Procedures used for bacteriological analyses were in accordance with Standard Methods and with Identification of Enterobacteriaceae by Edwards and Ewing. Bacteriological analysis of sewage samples were initiated within three hours of collection. Sewage samples were collected in the field in 3 oz. sterile screw-capped bottles by the pond technicians. Specimens were transferred to the laboratory

TABLE 3.4: ANNUAL PRECIPITATION (INCHES/MONTH)

Date 1969 - 1973	Inches	Date 1969 - 1973	Inches
January	3.81	July	6.88
February	.48	August	8.01
March	.97	September	10.05
April	5.85	October	11.33
May	8.78	November	11.21
June	10.12	December	4.88

5-Year Monthly Average = 6.89

TABLE 3.5: ANNUAL SOLAR RADIATION (LYS/DAY)

Date 1969 - 1973	LYS/day	Date 1969 - 1973	LYS/day
January	424	July	340
February	481	August	337
March	468	September	337
April	433	October	345
May	341	November	312
June	326	December	354

5-Year Monthly Average = 377

TABLE 3.6: ANNUAL RELATIVE HUMIDITY (%)

Date	Daily Average		
1969 - 1973	Maximum	Minimum	Monthly Average
January	97	55	82
February	97	48	77
March	98	46	76
April	98	51	80
May	98	64	81
June	97	68	88
July	98	69	89
August	99	70	90
September	99	69	90
October	99	70	90
November	98	69	90
December	97	61	86
5-Year Average	98	62	85

TABLE 3.7: ANNUAL AIR TEMPERATURE (°F)

Date 1969 - 1973	Daily Average Maximum	Daily Average Minimum	Monthly Average
January	89	74	79
February	92	72	80
March	92	73	81
April	91	73	80
May	89	76	81
June	89	75	81
July	89	74	80
August	88	74	80
September	87	74	79
October	86	74	78
November	85	73	78
December	87	73	78
5-Year Average	89	74	79

TABLE 3.8: ANNUAL WIND SPEED AND DIRECTION

Month 1969-1973	Prevailing Wind Direction	Average Hourly Speed (mph)	Average Maximum	
			Hourly Speed (mph)	Concurrent Direction
Jan.	NNW	2	8	N
Feb.	NNW	2	9	NW
Mar.	NNW	2	10	WNW
Apr.	NNW	2	11	WNW
May	NW	3	12	NW
Jun.	NW	3	12	NE
Jul.	NW	2	8	NW
Aug.	NW	2	6	NW
Sep.	S	1	7	SSE
Oct.	S	1	6	S
Nov.	NW	1	6	SW
Dec.	NW	1	7	NNE
5-Year Average	NW	2	9	NW

TABLE 3.9: ANNUAL EVAPORATION (TOTAL INCHES/MONTH)

Month	Evaporation*
Jan.	4.851
Feb.	5.894
Mar.	6.565
Apr.	5.928
May	4.119
Jun.	3.043
Jul.	3.345
Aug.	2.998
Sept.	2.485
Oct.	2.972
Nov.	3.104
Dec.	3.007
	48.311

*Five-year monthly averages

and processed no later than 3 hours after collection. Ten-fold dilutions (10^{-1} through 10^{-6}) of the samples were prepared in sterile buffered water. To favor an even suspension, dilutions were mechanically agitated in a Vortexganic agitator for no more than 10 seconds. Before inoculation, dilutions were agitated again for 5 seconds.

Identifications of Enterobacteriaceae (Qualitative and Quantitative Counts): Columns of 0.01 ml of each dilutions were streaked on the following agar media by calibrated bacteriological loops: Salmonella-Shigella (SS), MacConkey (MC), and Eosin Methylene Blue (EMB). For the qualitative isolations of enterobacteriaceae, 5 ml of the original wastewater samples were placed in Selenite broth. All inoculated media were incubated at 37°C. After incubation for 18 hours, aliquots of the Selenite Media were streaked on a second set of SS, MC, and EMB agar plates.

Colony counts were rounded off to the nearest log. Representative colonies were picked from plates of all dilutions. Up to 10 non-lactose-fermenting colonies of all types and sizes from each plate with growth were transferred to triple-sugar-iron agar (TSI) slants. Lactose-fermenting colonies from MC and typical-looking coliform colonies from EMB were subcultured in TSI agar. All TSI agar slants were incubated 24 hours.

Preliminary screening and identifications were carried out by inoculation of Christensen's urea, Simmon's citrate, and semisolid agar, and by the IMVIC reaction. Where pathogenic colonies were suspected, the identification was made by agglutination with polyvalent and group-specific antisera. All cultures identified according to the above procedures were further studied by biochemical tests, while those identified as Salmonella were submitted to the Center for Disease Control, Atlanta, Georgia, for confirmation.

Standard Plate Count (Total Colony Count): For each sample, 1 ml volume of each dilution was placed in petri dishes and 15 ml of melted tryptone glucose extract agar added in each petri dish. After thorough mixing of the contents of each dish, they were allowed to solidify and were immediately incubated. One set of plates were incubated at 37°C and another at 25°C. For plates incubated at 37°C, the counts were made after 24 hours, for those incubated at 25°C, after 48 hours. Plates showing 30 to 300 colonies were considered for determining Standard Plate Count and were made with the aid of a Quebec colony counter. Results were recorded as number of colonies per ml.

Fecal Coliform Count: In order to differentiate between coliforms of fecal origin and coliforms from other sources, a modification of the Fecal Coliform Test utilizing EC Medium was used. At least 5 typical coliform colonies were picked from each EMB plate dilution and transferred to TSI agar slants. After incubation, cultures showing typical reactions on TSI agar were planted in lactose broth fermentation tubes and incubated. After 24 hours if gas was not produced, tubes were re-incubated for another 24 hours. A loopful of medium from each fermentation tube showing gas was transferred to an EC medium fermentation tube and incubated in a water bath at 44.5 ± 0.2 C° for 24 hours.

All tubes were placed in the water bath within 30 minutes after plating. Gas production in each fermentation tube within 24 hours or less was considered a positive reaction indicating fecal origin. Failure to produce gas in EC medium constituted a negative reaction indicating coliforms from other sources. Fecal coliform and non-fecal coliform densities were calculated by multiplying the number of colonies picked from each dilution of EMB plates and characterized, times the appropriate dilution factor. Coliform organisms were further differentiated by means of the IMVIC reactions.

The bacteriological aspects of this study were divided into several phases or categories. In all the phases, samples were collected in a manner like the BOD. The first phase was an attempt to detect presence of pathogenic enterobacteriaceae (Salmonella, Shigella, enteropathogenic Escherichia coli and Arizona). The second phase was to determine the different kinds and numbers of the nonpathogenic bacteria groups of the enterobacteriaceae family which were present in the wastewater. A third category was to estimate the total colony counts of bacteria per ml when incubated at both 25°C and 37°C. A fourth category was to differente total coliforms, fecal coliforms and non-fecal coliforms. A final category was to make microscopic observations of the wastewater to determine if Bacilli gram positive or gram negative organisms, yeast or Cocci gram positive or gram negative organisms were present. Also analyses were done the last year of the project to determine if Vibrio parahaemolyticus could be isolated. It could not.

In all phases samples were collected by taking grab samples from each pond influent and effluent. All bacteria sampling was conducted on a weekly basis.

Bacteria analyses for members of the enterobacteriaceae family were begun in February, 1967. The analyses were quantitative and qualitative through December, 1970. From January, 1971, until project termination only qualitative analyses were done. Of the enterobactereaceae which produce diarrheal diseases, only Salmonella was isolated and always in quantities of less than ten organisms per ml. Shigella, Arizona, and enteropathogenic Escherichia coli were never isolated. The non-pathogenic enterobacteriaceae isolated were Enterobacter sometimes referred to as Aerobacter, Escherichia coli, Klebsiella, Proteus, Intermediate coliforms, and Providence. These organisms were identified even though they are not pathogenic because they constitute the majority of the intestinal flora in man and animals. Pseudomonas and Alcaligenes were also identified because they form part of the fecal flora and had to be isolated from those belonging to the enterobacteriaceae family.

Total colony counts were made for the duration of the project. From February through August, 1972, the samples were incubated at both 25 and 37°C. The standard plate count at 37°C measures a heterogeneous group of bacteria under conditions which favor the growth of bacteria whose natural habitat and optimum environment is in the bodies of warm-blooded animals. The 25°C plate count measures another group of bacteria which develop under conditions of nature outside of the animal body. After August, 1972, only 37°C plate counts were determined.

The 25°C plate counts were discontinued in August, 1972, so that determination for total coliforms, fecal coliforms and *Escherichia coli* could be made. The differentiation in these coliforms was determined from September, 1972, through December, 1973.

Microscopic observations of the wastewater were made from June, 1970, through September, 1972. These observations were made so that some insight could be gained into which organisms comprised the group of unidentified organisms reported for each sample.

3.3. Performance Evaluations

Thus far, the research has been discussed in terms of the four major operational phases which are divided by time. The data will now be presented in a slightly different manner so that it might be more meaningful. Performance evaluations of single-celled ponds with a depth of four feet, five feet and six feet, respectively, will be presented. Next, performance evaluations of two ponds in series and of three ponds in series, in that order, will be presented. A discussion of single-celled ponds and of multiple-celled pond systems will then be presented. A more extensive evaluation of the pond systems which will present performance equations, conclusions and recommendations will follow in Chapters 4 and 5.

3.3.1. Evaluation of a Four-Foot Pond

Pond 2 was operated as a single-celled, four-foot pond between January, 1969, and August, 1972. Pond 1 was operated as a single-celled pond having a four-foot depth from August, 1971 to August, 1972. Both Ponds 1 and 2 were loaded at approximately 250 lbs. BOD/acre/day until January, 1972. At this time, the BOD loading on Pond 1 was increased until Pond 1 failed. (The BOD parameter was used as the controlling parameter as described in this chapter under Methods and Materials.) Simultaneously, the BOD loading to Pond 2 was decreased.

Between January, 1969, and January, 1972, the BOD loading ranged from 149 to 551 lbs./acre/day with an average loading of 274 lbs./acre/day. The corresponding theoretical detention times were 11.3, 2.9 and 6.5 days. The corresponding percent BOD removals were 76, 42 and 62. From January, 1972, to August, 1972, the BOD loading ranged from 106 to 740 lbs. BOD/acre/day. The corresponding theoretical detention times were 17.4 and 1.8 days. The corresponding percent BOD removals were 76 and 48. At the 750 lbs. BOD/acre/day loading, Pond 1 began to become anaerobic, creating a situation where the pond became a primary sedimentation unit with a BOD removal of 36 percent. The BOD loadings were decreased and Pond 1 required two months to become a stabilized facultative pond.

The percent BOD removal was calculated using mg/l instead of lbs./acre/day because the ponds experienced a large amount of exfiltration. By calculating removals using mg/l, the most conservative figures are reported.

The influent COD values ranged from 173 to 641 mg/l, with an average of 298 mg/l. The percent removal of COD ranged from 13 to 75, with an average removal of 46 percent.

Tables 3.10-3.13 show the concentrations and/or removals for the different parameters. For more detailed presentation of the data, see Appendix II.

3.3.2. Evaluation of a Five-Foot Pond

When Ponds 1 and 2 were placed in series, the first pond (Pond 2) in the series was a five-foot pond. The time period of this operation was from September, 1972, to July 18, 1973. For purposes of comparison this five-foot pond will now be presented as a single-celled, five-foot pond.

The average monthly theoretical detention time for this pond ranged from a low of 2.2 days to a high of 7.3 days. The results of the operation of the five-foot pond will now be presented in tabular form. See Tables 3.14-3.17. Also, for a more detailed presentation of the data, see Appendix III.

3.3.3. Evaluation of a Six-Foot Pond

A single-celled pond was operated at a six-foot depth from the project beginning through March, 1971. The monthly average theoretical detention time ranged from 4.8 to 14.0 days with an average DT of 9.5 days. The data for the single-celled, six-foot pond is presented in tabular form in Tables 3.18 through 3.21. Detailed data is shown in Appendix IV.

TABLE 3.10: ORGANICS REMOVAL IN 4 FT. PONDS

Parameter	Time Period	Influent Conc*		Percent Removal	
		Range	Avg	Range	Avg
BOD	Jan. '69-Jan. '72	149 to 551	274	42 to 76	62
	Jan. '72-Aug. '72	106 to 740		48 to 76	
COD	Jan. '69-Aug. '72	173 to 641	298	13 to 75	46

*Concentrations are expressed in mg/l for all parameters except BOD which is expressed in lbs/acre-day.

TABLE 3.11: PHYSICAL AND CHEMICAL CHANGES IN 4 FT. PONDS

Parameter	Influent Conc Range	Range of Percent Removals
TS	364 to 1102	-40 to 66
VS	203 to 531	-34 to 85
Acidity*	44 to 70	-19 to 58
Alkalinity*	95 to 150	-62 to 23
Organic Nitrogen	17 to 45	13 to 66
Nitrate	.10 to .35	-44 to 50
Nitrite	0 to .0038	0
Ammonia	8.6 to 36.3	0 to 80
Total Phosphates	25.1 to 33.4	-41 to 9
Ortho-Phosphates	16.5 to 32.4	-98 to 10

*Expressed in mg/l as $CaCO_3$

Note: Values shown are for the period February 1969 - August 1972.

TABLE 3.12: TOTAL PLATE COUNTS (% REMOVAL)

Total Plate Count	Number of Samples with Indicated % Removals						
	<0	0-20	20-40	41-60	61-80	81-90	>90
@ 25°C	15	8	16	27	66	54	33
@ 37°C	33	32	28	26	55	37	10

TABLE 3.13: BACTERIAL GROUPS (COUNTS/ml)

37°C Bacterial Group	Number of Samples with Indicated Counts/ml $<10^2$	10^2	10^3	10^4	10^5	$>10^5$
Enterobacter						
Inf	21	9	23	27	9	1
Eff 2	41	18	20	9	3	2
Alcaligenes						
Inf	16	13	23	23	15	0
Eff 2	13	22	22	30	5	1
Escherichia						
Inf	0	0	5	31	40	9
Eff 2	1	0	34	40	17	1
Klebsiella						
Inf	18	8	27	30	6	1
Eff 2	66	11	12	7	1	--
Pseudomonas						
Inf	40	14	18	17	1	0
Eff 2	30	18	29	13	2	1
Proteus						
Inf	20	6	23	31	9	1
Eff 2	52	13	21	5	0	2
Intermediate Coliforms						
Inf	2	11	41	27	8	1
Eff 2	5	17	61	7	3	0
Providence						
Inf	46	13	23	8	0	0
Eff 2	52	12	18	1	0	0

TABLE 3.14: ORGANICS REMOVAL IN 5 FT. POND

Parameter	Influent Conc*		Percent Removal	
	Range	Avg	Range	Avg
BOD	243 to 599	344	32 to 76	57
COD	155 to 267	207	29 to 62	40

*Same footnote placed on Table 3.11

TABLE 3.15: PHYSICAL AND CHEMICAL CHANGES IN 5 FT. POND

Parameter	Range of Influent Conc	Range of Percent Removals
TS	389 to 666	-33 to 42
SS	.367 to 2.041	27 to 66
Alkalinity*	140 to 166	- 5 to 17
Organic Nitrogen	17.9 to 41.6	11 to 54
Nitrate	.05 to .29	-100 to 73
Ammonia	8.7 to 26.5	10 to 62
Ortho-Phosphate	14.7 to 41.8	-102 to 15

*Expressed in mg/l as $CaCO_3$

TABLE 3.16: TOTAL COLONY REMOVALS (%)

37°C Total Plate Count	Number of Samples with Indicated % Removals						
	<0	0-20	21-40	41-60	61-80	81-90	>90
Pond 2	7	5	6	4	12	7	1

TABLE 3.17: COLIFORM REMOVALS (%)

Aug. 30/72 - Jul. 18/73

37°C Total Plate Count	Number of Samples with indicated % Removals 0	0-39	40-59	60-79	80-89	90-99	99
Total Coliforms							
Pond 2	3	1	2	5	4	13	9
Fecal Coliforms							
Pond 2	4	2	--	--	3	15	11
E. coli							
Pond 2	6	2	--	--	1	7	5

TABLE 3.18: ORGANICS REMOVAL IN 6 FT. POND

Parameter	Influent Conc*		Percent Removal	
	Range	Avg	Range	Avg
BOD	119 to 441	230	40 to 69	57
COD	251 to 585	367	35 to 53	44

*Same footnote as for Table 3.11

TABLE 3.19: PHYSICAL AND CHEMICAL CHANGES IN 6 FT. POND

Parameter	Range of Influent Conc	Range of Percent Removals
TS	436 to 628	-28 to 12
VS	203 to 320	-29 to 26
Acidity*	44 to 70	-20 to 45
Alkalinity*	106 to 130	-43 to 7
Organic Nitrogen	17.1 to 33.8	9 to 48
Nitrate	0.12 to 0.24	-24 to 30
Nitrite	0 to .0038	0
Ammonia	8.6 to 36.3	28 to 61
Total Phosphate	25.1 to 33.4	-14 to 4
Ortho-Phosphate	24.8 to 32.4	-13 to 4

*Expressed in mg/l as $CaCO_3$

TABLE 3.20: BACTERIA GROUPS (COUNTS/ml)

37°C Bacterial Group	Number of Samples with Indicated Counts/ml $<10^2$	10^2	10^3	10^4	10^5	$>10^5$
Enterobacter						
Inf	21	9	23	27	9	1
Eff 1	56	7	21	5	4	0
Alcaligenes						
Inf	16	13	23	23	15	0
Eff 1	22	23	27	15	4	2
Escherichia						
Inf	0	0	5	31	40	9
Eff 1	15	3	38	27	7	3
Klebsiella						
Inf	18	8	27	30	6	1
Eff 1	67	7	15	3	0	1
Pseudomonas						
Inf	40	14	18	17	1	0
Eff 1	46	16	21	8	1	1
Proteus						
Inf	20	6	23	31	9	1
Eff 1	51	18	7	6	1	0
Intermediate Coliforms						
Inf	2	11	41	27	8	1
Eff 1	23	13	49	7	1	0
Providence						
Inf	46	13	23	8	0	0
Eff 1	68	10	13	2	0	0

TABLE 3.21: TOTAL COLONY REMOVAL (%)

Total Plate Count	Number of Samples with Indicated % Removal						
	<0	0-20	21-40	41-60	61-80	81-90	>90
Incubated at 25°C	9	5	12	9	23	24	14
Incubated at 37°C	14	11	23	17	18	13	3

3.3.4. Two Ponds Operated in Series

In September, 1972, Ponds 2 and 1 were placed in series. The first pond, Pond 2, was operated at a five-foot depth while Pond 1 was operated at a four-foot depth. This two pond system was in operation until July 18, 1973.

The monthly averaged theoretical DT for this pond system ranged from 3.9 to 12.9 days while having an average DT of 7.7 days. The data for the two pond system is presented in Tables 3.22 through 3.25. Detailed data is shown in Appendix V.

3.3.5. Three Ponds Operated in Series

On July 19, 1973, construction of a small anaerobic pond, Pond 3, was completed, and the pond was placed in a series operation with Ponds 2 and 1. The flow was from Pond 3 to Pond 2 and finally to Pond 1. The three pond system was operated through December 31, 1973, at which time the testing phase of the project was terminated.

The monthly averaged theoretical DT for this pond system ranged from 5.5 to 10.6 days with an average DT of 8.8 days. The parameter data which was recorded is shown in Tables 3.26 through 3.29. Detailed data is presented in Appendix VI.

TABLE 3.22: ORGANICS REMOVAL IN TWO-POND SYSTEM

Parameter	Influent Conc*		Percent Removal	
	Range	Avg	Range	Avg
BOD	135 to 337	194	48 to 78	67
COD	155 to 267	209	29 to 59	42

*Same footnote placed on Table 3.11

TABLE 3.23: PHYSICAL AND CHEMICAL CHANGES IN TWO POND SYSTEM

Parameter	Range of Influent Conc	Range of Percent Removals
TS	389 to 666	-26 to 48
SS*	0.367 to 2.982	19 to 80
Alkalinity**	114 to 166	-18 to 22
Organic Nitrogen	17.9 to 41.6	7 to 61
Nitrate	.05 to .29	-100 to 66
Ammonia	8.7 to 26.5	-23 to 39
Ortho-Phosphate	14.7 to 41.8	-114 to 40

*Filter used was larger than recommended for SS test

**Expressed in mg/l as $CaCO_3$

TABLE 3.24: TOTAL COLONY REMOVAL (%)

Total Plate Count	Number of Samples with Indicated % Removal						
	<0	0-20	21-40	41-60	61-80	81-90	>90
@ 37°C	2	2	9	5	8	7	9

TABLE 3.25: COLIFORM REMOVAL (%)

	Number of Samples with Indicated % Removal						
	<0	0-39	40-59	60-79	80-89	90-99	>99
Total Coliforms	2	2		1	4	15	14
Fecal Coliforms	4	5		--	--	13	11
E. coli	7	1		--	--	6	7

TABLE 3.26: ORGANICS REMOVAL IN THREE POND SYSTEM

Parameter	Influent Conc*		Percent Removal	
	Range	Avg.	Range	Avg.
BOD	105 to 143	143	59 to 83	75
COD	211 to 352	265	50 to 68	60

*Same footnote as for Table 3.11

TABLE 3.27: PHYSICAL AND CHEMICAL CHANGES IN THREE POND SYSTEMS

Parameter	Range of Influent Cone	Range of Percent Removals
TS	---	-129 to 16
Settleable Solids*	---	90 to 98
Alkalinity	131 to 157	5 to 25
Organic Nitrogen	13.1 to 34.7	34 to 79
Nitrate	.06 to .10	- 50 to 14
Ammonia	12.2 to 20.8	60 to 87
Ortho-Phosphate	22.4 to 31.2	-114 to 17

*Percent removal of settleable solids was analyzed only for Pond 3

TABLE 3.28: TOTAL COLONY REMOVALS (%)

Total Plate Count	Number of Samples with Indicated % Removals						
	<0	0-20	21-40	41-60	61-80	81-90	>90
@ 37°C	3	1	3	3	5	3	4

TABLE 3.29: COLIFORM REMOVALS (%)

	Number of Samples with Indicated % Removals						
	<0	0-39	40-59	60-79	80-89	90-99	>99
Total Coliforms	--	--	--	--	--	6	15
Fecal Colifroms	--	--	--	--	--	7	10
E. coli	--	--	--	--	--	7	6

3.3.7. Supplemental Studies

A conglomeration of supplemental studies to the field ponds was undertaken. These studies took varying degrees of time and looked at such things as typhoid die-offs, effects of the effluent wastewater on receiving streams, pond reaction to hydraulic and pesticide shock loadings, mosquito breeding, sludge accumulation and abandoned stabilization ponds.

In view of the periodic presence of Salmonella organisms in the wastewater effluent, a series of experiments was initiated to determine the fate of a pathogen (S. typhi) by adding a known dosage of this test organism in a 60 gallon tank full of wastewater, constructed in such a way that conditions present might simulate those in the larger experimental ponds. Daily samples of wastewater were retrieved from the tank and cultured for S. typhi. Tentative results indicated that when the tank was seeded with a low dosage (3×10^9 organisms/gal.), the pathogen could not be recovered. Daily cultures were made for 15 days. With a higher dose (12×10^9 organisms/gal.), the pathogen was recovered for only 2 days and both times it was from the bottom sludges.

Having no references on a study of this nature, it was necessary to choose a dosage at random. The number, 3×10^9 organisms/gal. was picked because it just seemed like it would be a good number and would satisfy the needs of the experiment.

Besides the two typhoid studies mentioned, each time during the full course of the project that a S. typhi was isolated from a sample the sample was saved. The *S. typhi* survived in the samples which were kept at room temperature from 1 to 14 days. Most of the samples were negative before five days had past.

Research done by others (Cody and Tisher, 1965) reports the survival time of *S. typhi* in facultative ponds to be about 30 hours; and in an anaerobic column, the *S. typhi* survived two days for 500 lbs. BOD/acre/day loadings and eleven days for 6,000 lbs. BOD/acre/day loadings. As a result of the short detention times for this project's pond systems, the occassional occurrence of *S. typhi* in the pond effluents is to be expected.

A study was also undertaken to determine the effects of this project's effluent wastewater on different receiving waters. Effluent wastewater was added to each fresh, brackish, and salt water so that 1, 5, and 10 percent of the total volumes were wastewater. Both algae and total coliform counts were taken. The coliforms survived 3 days in both the salt and brackish waters. The coliforms survived 6 days in the fresh water. The algae had a higher die-off rate in the salt water than in the brackish water and a higher die-off rate in the brackish water than in the fresh water.

These results are what one would expect. They do show though that the quality and quantity of effluent wastewater allowed to enter a receiving body of water should depend on the receiving stream.

Stock loadings were investigated. The military uses a large number of pesticides and most can be placed into the following classes:

organochlorine, organophosphate, and carbamate insecticides; and herbicides, many of which are organochlorine compounds.

It was believed that organophosphate, which includes diazinon, chlorpyrifos, malathion, and naled, is the most commonly used insecticide in the military. Therefore, 48 percent emulsifyable diazinon was chosen for the tests.

The diazinon was batch loaded into two 55-gallon drums which had been baffled, filled with wastewater and stabilized. The detention time of the bench scale ponds was 10 days. The diazinon when added to the two drums produced diazinon concentrations of 1,000 and 1,500 mg/l. The only observation made for the algae. This was the result of the chemical interference caused by the pesticide.

One day after inoculation the algae was still present, but their numbers were decreased. Algae was present on the third day after inoculation, but it appeared either dead or immobile. This conditions continued until the eighth day at which time there was a small amount of movement. On the ninth day the pond which had been inoculated with 1,000 mg Diazinon/ml appeared normal. The pond which had been inoculated with 1,500 mg Diazinon/ml did not appear normal until the eleventh day.

It appears that these high concentrations of pesticides can knock a pond out for a period approximately equivalent to its detention time. This is a result of the pesticide having little or no residual and a result of the bottom sludges not being significantly effected.

Stabilization ponds are very resistant to hydraulic shock loadings. These observations were made from the normal operation of the larger experimental ponds. Many daily flows, resulting from heavy rainfalls, equalled $1\frac{1}{2}$ times the total volume of the stabilization ponds with no adverse effects. The ponds resistance to hydraulic shock loadings can further be illustrated by observing the theoretical detention times shown in Appendix II. For average monthly detention time of 2 days BOD removals for the month averaged approximately 50 percent. As soon as the flows were decreased the removals increased.

Several other observations were made during the course of this project one of which was mosquito breeding. Larvae and adult mosquito counts on a weekly basis were taken for over a year's period. While adult man-biting mosquitoes were found in the light traps, no man-biting mosquitoes were found in larvae dips taken from the ponds.

It was also observed that hundreds of larvae could be dipped from the ponds not only when grass grew within the water's edge but also when the grass was allowed to get over a couple of feet high around the pond edges giving the mosquitoes shade and protection from the wind. Tall grass is a much greater problem in the tropics than in colder climates. In Panama, the Cane Grass can grow to 15 feet. It was found that by cutting the grass by means of a lawn mower shorter grasses choked out the Cane Grass and the mosquito larvae disappeared.

The last two observations were sludge build-up within the ponds and an abandoned pond. After a little over two years of operation at an approximate loading of 200 lbs. BOD/acre/day a single-celled pond was drained. The sludge build-up on the pond's bottom averaged 4 inches. The sludge build-up in the small undrained anaerobic pond was measured after 6 month's operation. While the loadings were between 5,000 and 11,000 lbs. BOD/acre/day the sludge build-up was only 12 inches. This may be the result of either or both of two factors. The flow was rapid enough that it may have washed the sludge from the pond after it accumulated to a certain level. The other explanation is that sludge in an anaerobic pond builds up very rapidly at first, but then it reaches a point of equilibrium where the decomposition of solids takes place as fast as the solids accumulate.

A pond was abandoned and semi-monthly algae samples taken for six months. At the end of six months the algae being identified were 95 percent polluted water algae. At this time the following bacterial results were observed:

Total Plate Count = 3.5×10^4

E. Coli were present

Coliforms were present

Providence was present

No pathogens were isolated

No other Enterobacteriaceae were isolated

Chapter 4

DATA REDUCTION

As was shown in Chapter 3, the experimental design involved the collection of a tremendous amount of data over the 5-year experimental period. The presentation in Chapter 3 was in the format of traditional analyses of the data. The purpose of Chapter 4 is to discuss the subjection of the data to computational analysis and to arrive at, first, a series of correlations matrices, and secondly, through stepwise regression at a series of possible equations relating the variables. This computational analysis was accomplished in two segments; the first segment involved the analysis of all collected data for the period February, 1969, through January, 1972 (single pond operation at 4 ft. and 6 ft. depths), and the second segment involved the selective analysis of data sub-groups organized by the four experimental phases of the project.

4.1. Analysis of All Data for February, 1969 - January, 1972

The 28 variables studied are listed in Table 4.1, and they range from flow to BOD and alkalinity through depth, nitrates, phosphates, rainfall, air temperature, and others. The correlation matrix for the six-foot pond at the influent is shown in Appendix VII. The interpretation of this matrix will be made later, but just to

TABLE 4.1: VARIABLES UTILIZED IN COMPUTATIONAL ANALYSIS

Variable No.	Variable Name
1	Flow
2	BOD_{20}
3	BOD_{30}
4	Acidity
5	Alkalinity
6	pH
7	DO
8	Water temperature
9	Total solids
10	Volatile solids
11	Total phosphate
12	Orthophosphate
13	Organic nitrogen
14	Ammonia
15	Nitrate
16	Nitrite
17	Depth
18	Phylum algae
19	Class algae
20	Genus algae
21	Species algae
22	Plankton count
23	Rainfall
24	Solar radiation
25	Relative humidity maximum
26	Relative humidity minimum
27	Air temperature maximum
28	Air temperature minimum

illustrate, variable 1 (flow) and variable 16 (nitrite) have the highest degree of correlation, 0.650 (row 1 and column 16). The highest correlation of row 2 is found in column 3, which is a correlation between BOD_{20} and BOD_{30}. The highest correlation in row 3 similarly, is, of course, column 2. Similarly, Appendix VIII is a correlation matrix for the effluent from the six-foot pond. Selected two variable correlations are shown in Tables 4.2 and 4.3, for example, BOD_{20} is a function of variable 3 and 26, or BOD_{30} and minimum relative humidity. The dissolved oxygen at the influent point is a function of variables 25 and 19, or maximum relative humidity and class of algae.

Tables 4.4 and 4.5 illustrate the highest correlation for variables 1-28. For example, flow is correlated to variable 16, which is nitrite, and variable 19, which is the class of algae. This is different than Tables 4.2 and 4.3 which indicated the results of development of equations. Tables 4.6 and 4.7 do the same thing for the effluent from the four-foot pond as do Tables 4.3 and 4.5 for the six-foot pond.

Analysis of the composite data in the fashion shown in Tables 4.2 through 4.7 indicated many unexplainable relationships. This analysis was of limited value since there were many voids in the data and companion data pieces often did not exist. The next step was the creation of two additional variables, the percentage reductions in BOD_{20} and BOD_{30}. As shown in Table 4.8, these new variables

TABLE 4.2: SELECTED TWO VARIABLE CORRELATIONS FOR 6-FOOT POND INFLUENT

$$\text{BOD}_{20} = 1.17153 + 0.52357X_3{}^{*} - 0.52633X_{26}$$

$$\text{BOD}_{30} = -8.98431 + 1.22303X_2 + 2.96718X_{25}$$

$$\text{pH} = 11.84016 - 3.52967X_{25} - 0.46388X_{19}$$

$$\text{DO} = 392.84302 - 392.88354X_{25} + 22.48769X_{19}$$

$$\text{Water Temp.} = -201.04805 + 162.73789X_{25} + 6.29978X_6$$

$$\text{Total P.} = -12.20316 - 7.86074X_{25} + 2.40837X_6$$

$$\text{Plankton count} = -1082503.00000 + 67510.18750X_6 + 541174.37500X_{25}$$

$$\text{Species algae} = -130.54680 + 156.28778X_{25} - 22.00789X_{26}$$

$$\text{Class algae} = -3.08521 + 4.16492X_{25} - 0.26241X_{26}$$

$$\text{Phylum algae} = 29.85103 - 48.39455X_{25} + 15.14501X_{19}$$

*See Table 4.1 for identification of variable number.

TABLE 4.3: SELECTED TWO VARIABLE CORRELATIONS FOR 6-FOOT POND EFFLUENT

$$BOD_{20} = 4.11666 + 0.69226X_3{}^{*} + 1.14120X_{26}$$

$$BOD_{30} = 1.38926 + 0.75046X_2 - 1.41314X_{25}$$

$$pH = 35.75253 - 30.17816X_{25} + 0.06106X_{19}$$

$$DO = -26.44474 + 26.07127X_{25} + 0.79056X_{19}$$

$$\text{Plankton count} = -3243238 + 8143.48X_6 + 3088702.0X_{25}$$

$$\text{Species algae} = 364.56 - 357.68X_{25} - 15.22X_{26}$$

$$\text{Phylum algae} = -149.96 + 153.68X_{25} + 12.5377X_{19}$$

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*See Table 4.1 for identification of variable numbers.

TABLE 4.4: HIGH CORRELATION VARIABLES FOR 6-FOOT POND INFLUENT

Variable		Correlation Variables	
1.	Flow	$.530X_{16}$,	$.376X_{19}$
2.	BOD_{20}	$.849X_{3}$,	$.546X_{11}$
3.	BOD_{30}	$.849X_{2}$,	$.341X_{13}$
4.	Acidity	$.657X_{5}$,	$-.361X_{1}$
5.	Alkalinity	$.657X_{4}$,	$.436X_{26}$
6.	pH	$.660X_{22}$,	$.453X_{8}$
7.	DO	$.384X_{20}$,	$.354X_{10}$
8.	Water temperature	$.453X_{6}$,	$.347X_{14}$
9.	Total solids	$.601X_{10}$,	$.266X_{6}$
10.	Volatile solids	$.601X_{9}$,	$.298X_{13}$
11.	Total phosphate	$.982X_{12}$,	$-.307X_{8}$
12.	Orthophosphate	$.982X_{11}$,	$-.318X_{19}$
13.	Organic nitrogen	$.596X_{14}$,	$-.431X_{16}$
14.	Ammonia	$-.691X_{16}$,	$.596X_{13}$
15.	Nitrate	$-.291X_{25}$,	$-.211X_{13}$
16.	Nitrite	$-.691X_{14}$,	$.633X_{21}$
17.	Depth	$.318X_{4}$,	$.248X_{27}$
18.	Phylum algae	$.984X_{19}$,	$.637X_{20}$
19.	Class algae	$.984X_{18}$,	$.704X_{20}$
20.	Genus algae	$.704X_{19}$,	$.637X_{18}$
21.	Species algae	$-.700X_{26}$,	$.638X_{16}$
22.	Plankton count	$.560X_{6}$,	$.500X_{15}$
23.	Rainfall	$-.566X_{14}$,	$-.510X_{5}$
24.	Solar radiation	$.481X_{27}$,	$-.386X_{26}$
25.	Relative humidity maximum	$-.449X_{28}$,	$.349X_{20}$
26.	Relative humidity minimum	$-.700X_{21}$,	$-.386X_{24}$
27.	Air temperature maximum	$.462X_{4}$,	$-.351X_{1}$
28.	Air temperature minimum	$.554X_{27}$,	$-.449X_{25}$

TABLE 4.5: HIGH CORRELATION VARIABLES FOR 6-FOOT POND EFFLUENT

Variable	Correlation Variables	
1. Flow	$.501X_{23}$,	$-.337X_{7}$
2. BOD_{20}	$.608X_{3}$,	$-.347X_{27}$
3. BOD_{30}	$.608X_{2}$,	$.352X_{12}$
4. Acidity	$.338X_{27}$,	$.267X_{12}$
5. Alkalinity	$.392X_{6}$,	$-341X_{24}$
6. pH	$.392X_{5}$,	$-.346X_{27}$
7. DO	$.763X_{21}$,	$-.312X_{25}$
8. Water temperature	$.404X_{6}$,	$-327X_{26}$
9. Total solids	$.789X_{10}$,	$.496X_{13}$
10. Volatile solids	$.789X_{9}$,	$.590X_{13}$
11. Total phosphate	$.543X_{14}$,	$.872X_{12}$
12. Orthophosphate	$.517X_{14}$,	$.872X_{11}$
13. Organic nitrogen	$.643X_{14}$,	$.590X_{10}$
14. Ammonia	$.643X_{13}$,	$.543X_{11}$
15. Nitrate	$.324X_{23}$,	$.300X_{22}$
16. Nitrite	$.421X_{13}$,	$.402X_{17}$
17. Depth	$.414X_{9}$,	$.414X_{9}$
18. Phylum algae	$.978X_{19}$,	$.504X_{20}$
19. Class algae	$.978X_{18}$,	$.579X_{20}$
20. Genus algae	$.579X_{19}$,	$.504X_{18}$
21. Species algae	$.763X_{7}$,	$-.610X_{25}$
22. Plankton count	$.368X_{20}$,	$-.364X_{18}$
23. Rainfall	$.501X_{1}$,	$-.312X_{11}$
24. Solar radiation	$.811X_{26}$,	$-.341X_{5}$
25. Relative humidity maximum	$-.610X_{21}$,	$-.347X_{2}$
26. Relative humidity minimum	$-.811X_{24}$,	$.302X_{20}$
27. Air temperature maximum	$.564X_{13}$,	$.461X_{11}$
28. Air temperature minimum	$.508X_{11}$,	$.483X_{12}$

TABLE 4.6: SELECTED TWO VARIABLE CORRELATIONS FOR 4-FOOT POND EFFLUENT

$$BOD_{20} = -1.13897 + .69842X_3{}^{*} + .19361X_6$$

$$BOD_{30} = 1.39252 - 1.17001X_{19} + .77305X_2$$

$$pH = 7.80314 - 1.21767X_{26} + 1.17918X_{19}$$

$$DO = -50.27263 + 14.56466X_{26} - 8.21177X_{19}$$

$$\text{Total P.} = -28.13573 - 14.71658X_{19} + 8.21177X_{26}$$

$$\text{Nitrate} = -7.36759 - 8.48910X_{19} - 2.83079X_3$$

$$\text{Phylum algae} = 8.22957 + 12.22346X_{19} + 1.35986X_1$$

$$\text{Class algae} = -0.63976 - .10845X_1 + .10042X_2$$

$$\text{Species algae} = -49.75432 - 58.00781X_{19} + 10.15963X_{26}$$

$$\text{Plankton count} = -184910.43750 + 186641.93750X_{19} + 39589.48828X_3$$

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*See Table 4.1 for identification of variable number.

TABLE 4.7: HIGH CORRELATION VARIABLES FOR 4-FOOT POND EFFLUENT

Variable	Correlation Variables	
1. Flow	$.552X_{23}$,	$.548X_{16}$
2. BOD_{20}	$.670X_{3}$,	$-0.258X_{17}$
3. BOD_{30}	$.670X_{2}$,	$-0.364X_{4}$
4. Acidity	$.379X_{5}$,	$-0.364X_{3}$
5. Alkalinity	$-0.480X_{24}$,	$-0.475X_{27}$
6. pH	$.769X_{7}$	$0.554X_{14}$
7. DO	$.769X_{6}$,	$.638X_{22}$
8. Water temperature	$.477X_{14}$,	$.404X_{7}$
9. Total solids	$.936X_{10}$,	$.275X_{11}$
10. Volatile solids	$.936X_{9}$,	$.382X_{5}$
11. Total phosphate	$.965X_{12}$,	$.812X_{13}$
12. Orthophosphate	$.965X_{11}$,	$.830X_{13}$
13. Organic nitrogen	$.830X_{12}$,	$.812X_{11}$
14. Ammonia	$-0.437X_{6}$,	$.352X_{4}$
15. Nitrate	$-0.335X_{5}$,	$-0.323X_{27}$
16. Nitrite	$-0.712X_{13}$,	$-0.662X_{12}$
17. Depth	$.334X_{11}$,	$.304X_{12}$
18. Phylum algae	$.983X_{19}$,	$.660X_{20}$
19. Class algae	$.983X_{18}$,	$.736X_{20}$
20. Genus algae	$.736X_{19}$,	$.660X_{18}$
21. Species algae	$.368X_{18}$,	$-0.321X_{27}$
22. Plankton count	$.716X_{7}$,	$.598X_{6}$
23. Rainfall	$.552X_{1}$,	$-0.338X_{13}$
24. Solar radiation	$-0.844X_{26}$,	$.733X_{27}$
25. Relative humidity maximum	0.0	0.0
26. Relative humidity minimum	$-0.844X_{24}$,	$-0.616X_{27}$
27. Air temperature maximum	$.733X_{24}$,	$-0.616X_{26}$
28. Air temperature minimum	$.576X_{12}$,	$.546X_{11}$

TABLE 4.8: ADJUSTED VARIABLES USED IN COMPUTATIONAL ANALYSIS

Variable No.	Variable Name
1	Flow
2	$\frac{BOD_{20(Influent)} - BOD_{20(Effluent)}}{BOD_{20(Influent)}}$
3	$\frac{BOD_{30(Influent)} - BOD_{30(Effluent)}}{BOD_{30(Influent)}}$
4	Acidity
5	Alkalinity
6	pH
7	DO
8	Water temperature
9	Total solids
10	Volatile solids
11	Total phosphate
12	Orthophosphate
13	Organic Nitrogen
14	Ammonia
15	Nitrate
16	Nitrite
17	Depth
18	Phylum algae
19	Class algae
20	Genus algae
21	Species algae
22	Plankton count
23	Rainfall
24	Solar radiation
25	Relative humidity maximum
26	Relative humidity minimum
27	Air temperature maximum
28	Air temperature minimum

replaced the old variables 2 and 3, namely, BOD_{20} and BOD_{30}. The correlation matrix for the influent and effluent of the six-foot pond is shown in Appendix IX, and the high correlation variables are contained in Table 4.9.

Therefore, analyses of all the data in the fashion described above indicated that additional data reduction would be necessary in order to develop meaningful relationships.

4.2 Selective Analysis of Data Sub-Groups

The first step in the selective analysis was to reduce the 28 variables to 6 more meaningful variables, and to reduce the approximately 60 months of data into aggregates of smaller groups that could be more easily manipulated. These data were then regressed against the BOD, COD, nitrogen, phosphorus, and coliform removals. The data was also arranged into loadings such as pounds of BOD per acre per day, pounds COD per acre per day, pounds nitrogen per acre per day (this includes both organic and ammonia) and pounds phosphorus per acre per day. Two other parameters were developed which were intended to represent volume and weather conditions, specifically. The volume representation was percent of exfiltration, and the weather representation the precipitation minus the evaporation divided by precipitation.

The data was grouped into five groupings, varying from six to eight items. The groupings were selected based on the experiments

TABLE 4.9: HIGH CORRELATION VARIABLES FOR 6-FOOT POND INFLUENT AND EFFLUENT

Variable		Correlation Variables		
1.	Flow	$.530X_{16}$,	$-0.433X_{14}$	
2.	BOD_{20}	$.721X_{3}$,	$.307X_{13}$	
3.	BOD_{30}	$.721X_{2}$,	$.365X_{16}$,	$-.327X_{28}$
4.	Acidity	$.657X_{5}$,	$-.475X_{23}$	
5.	Alkalinity	$.657X_{4}$,	$.436X_{26}$	
6.	pH	$.660X_{22}$,	$.453X_{8}$	
7.	DO	$.384X_{20}$,	$.354X_{9}$	
8.	Water temperature	$.453X_{6}$,	$.347X_{14}$	
9.	Total solids	$.601X_{10}$,	$-.277X_{19}$	
10.	Volatile solids	$.601X_{9}$,	$.354X_{7}$	
11.	Total phosphate	$.982X_{12}$,	$-.307X_{8}$	
12.	Orthophosphate	$.932X_{11}$,	$-.265X_{18}$	
13.	Organic nitrogen	$.596X_{14}$,	$-.431X_{16}$	
14.	Ammonia	$.596X_{13}$,	$-.691X_{16}$	
15.	Nitrate	$-.291X_{25}$,	$.272X_{28}$	
16.	Nitrite	$-.691X_{14}$,	$.638X_{21}$	
17.	Depth	$.318X_{4}$,	$.280X_{5}$	
18.	Phylum algae	$.984X_{19}$,	$.344X_{25}$	
19.	Class algae	$.984X_{18}$,	$.349X_{25}$	
20.	Genus algae	$.704X_{19}$,	$.637X_{18}$	
21.	Species algae	$.700X_{26}$,	$.638X_{16}$	
22.	Plankton count	$.660X_{6}$,	$-.424X_{20}$	
23.	Rainfall	$-.566X_{14}$,	$-.510X_{5}$	
24.	Solar radiation	$.481X_{27}$,	$-.386X_{26}$	
25.	Relative humidity maximum	$-.449X_{28}$,	$.349X_{19}$	
26.	Relative humidity minimum	$-.700X_{21}$,	$-.386X_{24}$	
27.	Air temperature maximum	$.462X_{4}$,	$.481X_{24}$	
28.	Air temperature minimum	$-.449X_{25}$,	$.554X_{27}$	

undertaken, namely the 4-ft., 5-ft. and 6-ft. single pond depths, and the two-pond and three-pond systems. The summary data utilized in this analysis is shown in Tables 4.10 through 4.14, respectively. The correlation matrices for 4-ft., 5-ft. and 6-ft. ponds, and the two-pond and three-pond systems are shown in Appendices X through XIV, respectively. The listing of variables in the matrices is in Table 4.15.

The summary equations for each of the five systems are shown in Tables 4.16 through 4.20. The R and R^2 values for these equations are shown in Table 4.21.

TABLE 4.10: SELECTED DATA SUB-GROUPS FOR COMPUTATIONAL ANALYSIS FOR 4-FOOT POND

% Removal						Loading (#/acre/day)				Inf-Eff / Inf	Prec-Evap / Prec
BOD	COD	N	Nitrate	P	*E. coli*	BOD	COD	N	P		
52	46	42	11	7	66	334	471	60	45	.5169	.5588
58	38	31	21	-5	62	223	531	48	58	.4338	.7205
68	36	45	-4	0	58	259	351	62	38	.4359	-4.3859
58	56	45	8	-20	89	284	328	41	21	.5962	-.6749
75	48	55	-6	-26	85	210	296	69	39	.7615	.7284
65	48	34	14	-26	99	260	323	48	36	.6650	-8.1934
72	67	30	-9	-21	48	256	1086	99	109	.6156	-.7694
53	38	39	1	-53	98	389	585	124	77	.5212	.6733

TABLE 4.11: SELECTED DATA SUB-GROUPS FOR COMPUTATIONAL ANALYSIS FOR 5-FOOT POND

% Removal						Loading (#/acre/day)				Inf-Eff	Prec-Evap
BOD	COD	N	Nitrate	P	*E. coli*	BOD	COD	N	P	Inf	Prec
65	36	38	1	-76	0	317	535	128	62	.1355	.7458
52	32	31	0	4	71	264	747	125	131	.0485	.6622
32	62	21	23	-24	70	456	1141	188	142	.1272	.3525
58	32	56	15	-15	99	599	430	136	50	.0430	-.0867
71	48	30	25	-56	47	239	394	81	60	-.0263	-8.0769
54	36	46	-69	-8	1	321	559	91	82	.0972	-1.0654
40	39	52	-100	14	97	264	439	142	47	.0616	.5806
76	43	29	-22	-102	99	334	437	64	39	.0727	.6978

TABLE 4.12: SELECTED DATA SUB-GROUPS FOR COMPUTATIONAL ANALYSIS FOR 6-FOOT POND

% Removal						Loading (lbs/acre/day)				Inf-Eff	Prec-Evap
BOD	COD	N	Nitrate	P	*E. coli*	BOD	COD	N	P	Inf	Prec
42	51	34	30	-8	95	306	338	26	29	.6438	.5746
62	44	55	-14	4	88	215	597	50	43	.6298	.7033
55	39	32	9	-14	30	278	303	41	30	.4512	.2910
52	53	57	27	-5	95	202	561	69	40	.6107	-5.0660
59	44	43	-15	-5	89	170	277	40	28	.6407	.5550
61	35	61	-13	-5	95	241	325	24	26.7	.7176	.7053
65	44	31	-24	-11	87	184	253	37	26.3	.7751	.4603
60	44	37	11	-12	88	255	482	51	38.0	.7321	-8.2360

TABLE 4.13: SELECTED DATA SUB-GROUPS FOR COMPUTATIONAL ANALYSIS FOR TWO-POND SYSTEM

% Removal						Loading (lbs/acre/day)				Inf-Eff	Prec-Evap
BOD	COD	N	Nitrate	P	*E. coli*	BOD	COD	N	P	Inf	Prec
73	50	36	10	-48	0	164	289	69	33	.4420	.7458
60	38	48	-29	-8	99	254	403	68	71	.2688	.6622
64	59	63	19	-19	0	337	613	102	77	.3530	.3525
71	29	38	-71	-27	46.5	194	232	73	25	.5085	-.0867
81	35	35	66	40	97	133	212	44	43	.5543	-8.0769
67	40	53	35	-3	0	173	303	47	44	.4112	-1.0654
48	36	43	23	11	95	168	204	51	26	.3942	.5806
78	54	62	-50	-114	99	188	253	56	16	.4725	.6978

TABLE 4.14: SELECTED DATA SUB-GROUPS FOR COMPUTATIONAL ANALYSIS FOR THREE-POND SYSTEM

% Removal						Loading (lbs/acre/day)				Inf-Eff	Prec-Evap
BOD	COD	N	Nitrate	P	*E. coli*	BOD	COD	N	P	Inf	Prec
75	54	43	0	-114	99	116	224	33	16	.4725	.6978
	50	62	-30	-47	55	109	261	50	35	.4553	.3424
74	53	45	-50	-28	99	151	378	52	44	.3958	.8911
83	68	61	-44	-20	99	240	706	82	45	.4003	.8370
81	68	57	0	2	93	132	316	27	28	.4818	.7913
79	63	81	14	17	99.9	105	313	48	32	.6928	.3634

TABLE 4.15: SUB-GROUP VARIABLES UTILIZED IN COMPUTATIONAL ANALYSIS

Variable No.	Variable Name
1	% Removal BOD
2	% Removal COD
3	% Removal Nitrogen (organic + ammonia)
4	% Removal Nitrate
5	% Removal Phosphorus
6	% Removal _E. coli_
7	BOD Loading
8	COD Loading
9	Nitrogen Loading
10	Phosphorus Loading
11	(Inf. - Eff.)/Inf.
12	(Prec. - Evap.)/Prec.

TABLE 4.16: SUMMARY PERFORMANCE EQUATIONS FOR THE SINGLE 4-FOOT POND

$$\% \text{ BOD Removal} = 88.094 - 0.186\ BOD_L + 0.458\ N_L - 0.851\left(\frac{P - E}{P}\right) + 6.920\left(\frac{I - E}{I}\right) - 0.633\ P_L + 0.046\ COD_L$$

$$\% \text{ COD Removal} = 2.378 + 56.837\left(\frac{I - E}{I}\right) + 0.101\ COD_L - 0.789\ P_L + 0.056\ N_L$$

$$\% \text{ N Removal} = 59.178 + 0.830\ COD_L + 0.736\left(\frac{P - E}{P}\right) + 2.826\left(\frac{I - E}{I}\right) + 0.492\ N_L - 0.820\ P_L - 0.093\ BOD_L$$

$$\% \text{ Nitrate Removal} = -5.474 - 0.931\ N_L + 0.181\ BOD_L + 1.432\ P_L - 0.104\ COD_L$$

$$\% \text{ P Removal} = 43.553 - 0.556\ N_L - 62.614\left(\frac{I - E}{I}\right) + 0.025\ COD_L$$

$$\% \text{ } \underline{E.\ coli} \text{ Removal} = -20.202 - 0.129\ COD_L - 0.379\ N_L + 107.994\left(\frac{I - E}{I}\right) + 0.244\ BOD_L + 1.078\ P_L$$

Where BOD_L = BOD loading in lb./ac./day.

N_L = Organic and ammonia nitrogen loading in lb./ac./day.

P = Precipitation in inches.

E = Evaporation in inches, when used with P.

I = Influent flow.

E = Effluent flow, when used with I.

P_L = Orthophosphate loading in lb./ac./day.

COD_L = COD loading in lb./ac./day.

TABLE 4.17: SUMMARY PERFORMANCE EQUATIONS FOR THE SINGLE 5-FOOT POND*

$$\%\ \text{BOD Removal} = 90.638 + 0.022\ \text{BOD}_L - 0.050\ P_L$$

$$\%\ \text{COD Removal} = 26.849 + 0.117\ \text{COD}_L - 1.523\left(\frac{P-E}{P}\right) - 0.520\ P_L - 0.019\ \text{BOD}_L - 64.358\left(\frac{I-E}{I}\right) - 0.36\ N_L$$

$$\%\ \text{N Removal} = 40.434 - 0.089\ \text{COD}_L + 0.207\ N_L + 1.115\left(\frac{P-E}{P}\right) + 0.213\ P_L + 0.027\ \text{BOD}_L$$

$$\%\ \text{Nitrate Removal} = -117.225 + 0.223\ \text{BOD}_L - 7.406\left(\frac{P-E}{P}\right) + 0.584\ P_L - 0.227\ N_L$$

$$\%\ \text{P Removal} = -79.345 + 0.886\ N_L - 197.609\left(\frac{I-E}{I}\right) + 3.423\left(\frac{P-E}{P}\right) - 0.014\ \text{BOD}_L + 1.397\ P_L - 0.248\ \text{COD}_L$$

$$\%\ \underline{E.}\ \underline{coli}\ \text{Removal} = 114.798 - 1411.879\left(\frac{I-E}{I}\right) + 15.744\left(\frac{P-E}{P}\right) - 0.014\ \text{BOD}_L + 0.356\ \text{COD}_L - 1.848\ P_L - 0.047\ N_L$$

*See Table 4.16 for identification of terms.

TABLE 4.18: SUMMARY PERFORMANCE EQUATIONS FOR THE SINGLE 6-FOOT POND*

$$\% \text{ BOD Removal} = 38.332 - 0.108\ BOD_L + 20.372\left(\frac{I-E}{I}\right) - 0.287\ N_L + 2.506\ P_L - 0.099\ COD_L$$

$$\% \text{ COD Removal} = -47.117 + 0.992\ N_L + 0.152\ BOD_L + 59.106\left(\frac{I-E}{I}\right) + 1.82\left(\frac{P-E}{P}\right) - 0.668\ P_L$$

$$\% \text{ N Removal} = 313.997 + 0.429\ COD_L - 6.644\ P_L - 0.347\ BOD_L - 133.620\left(\frac{I-E}{I}\right) - 1.385\ N_L - 3.053\left(\frac{P-E}{P}\right)$$

$$\% \text{ Nitrate Removal} = -54.899 + 0.443\ BOD_L + 1.683\ N_L - 6.269\ P_L + 0.222\ COD_L$$

$$\% \text{ P Removal} = 29.625 + 0.082\ COD_L + 0.303\left(\frac{P-E}{P}\right) - 19.005\left(\frac{I-E}{I}\right) - 0.099\ BOD_L - 0.416\ N_L - 0.474\ P_L$$

$$\% \text{ } \underline{E.}\ \underline{coli} \text{ Removal} = 52.546 + 140.600\left(\frac{I-E}{I}\right) + 0.334\ COD_L - 5.875\ P_L$$

---

*See Table 4.16 for identification of terms.

TABLE 4.19: SUMMARY PERFORMANCE EQUATIONS FOR THE TWO-POND SYSTEM*

$$\% \text{ BOD Removal} = 19.976 + 105.440\left(\frac{I-E}{I}\right) + 0.074\ COD_L - 0.101\ BOD_L$$

$$\% \text{ COD Removal} = 133.117 + 0.289\ COD_L - 1.633\ P_L - 0.232\ BOD_L + 0.291\ N_L - 208.932\left(\frac{I-E}{I}\right) - 5.440\left(\frac{P-E}{P}\right)$$

$$\% \text{ N Removal} = 14.456 + 0.264\ BOD_L - 1.059\ N_L - 0.491\ N_L + 0.137\ COD_L + 59.575\left(\frac{I-E}{I}\right) + 1.153\left(\frac{P-E}{P}\right)$$

$$\% \text{ Nitrate Removal} = 549.286 - 32.839\left(\frac{P-E}{P}\right) - 1094.866\left(\frac{I-E}{I}\right) - 1.548\ BOD_L + 0.902\ COD_L - 4.777\ P_L + 1.888\ N_L$$

$$\% \text{ P Removal} = -79.973 - 0.548\left(\frac{P-E}{P}\right) + 114.290\left(\frac{I-E}{I}\right) - 0.413\ COD_L + 3.332\ P_L$$

$$\% \text{ } \underline{\text{E. coli}} \text{ Removal} = 620.706 + 1.572\ N_L + 1.338\ BOD_L - 0.464\ COD_L - 40.550\left(\frac{P-E}{P}\right) - 1367.918\left(\frac{I-E}{I}\right) - 5.715\ P_L$$

*See Table 4.16 for identification of terms.

TABLE 4.20: SUMMARY PERFORMANCE EQUATIONS FOR THE THREE-POND SYSTEM*

$$\%\ \text{BOD Removal} = 14.469 + 27.244\left(\frac{P-E}{P}\right) + 73.942\left(\frac{I-E}{I}\right) + 0.071\ BOD_L - 0.160\ N_L - 0.149\ P_L + 0.027\ COD_L$$

$$\%\ \text{COD Removal} = 45.231 - 0.109\ COD_L - 0.709\ N_L + 34.448\left(\frac{I-E}{I}\right) - 11.766\left(\frac{P-E}{P}\right)$$

$$\%\ \text{N Removal} = 11.466 + 87.464\left(\frac{I-E}{I}\right) + 0.272\ P_L - 26.979\left(\frac{P-E}{P}\right) + 0.036\ COD_L$$

$$\%\ \text{Nitrate Removal} = -42.882 + 157.851\left(\frac{I-E}{I}\right) - 1.060\ P_L - 23.897\left(\frac{P-E}{P}\right) + 0.052\ COD_L - 0.954\ N_L + 0.189\ BOD_L$$

$$\%\ \text{P Removal} = -293.396 + 4.921\ P_L + 326.894\left(\frac{I-E}{I}\right) - 2.962\ N_L + 0.229\ COD_L$$

$$\%\ \underline{E.}\ \underline{coli}\ \text{Removal} = -85.264 + 122.170\left(\frac{P-E}{P}\right) + 194.613\left(\frac{I-E}{I}\right) + 0.969\ N_L - 0.586\ P_. - 0.069\ COD_L$$

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*See Table 4.16 for identification of terms.

TABLE 4.21: SUMMARY OF STATISTICAL PARAMETERS FOR PERFORMANCE EQUATIONS

System		Performance Parameter (%)					
		BOD Removal	COD Removal	Nitrogen Removal	Nitrate Removal	Phosphorus Removal	*E. coli* Removal
Single Pond - 4 ft.							
	R	0 991	0.997	0.953	0.950	0.810	0.897
	R^2	0.982	0.994	0.908	0.902	0.656	0.804
Single Pond - 5 ft.							
	R	0.885	0.999	0.900	0.708	0.812	1.000
	R^2	0.782	0.998	0.810	0.501	0.659	1.000
Single Pond - 6 ft.							
	R	0.778	0.734	0.991	0.921	0.981	0.889
	R^2	0.605	0.538	0.982	0.848	0.962	0.790
Two-Ponds							
	R	0.794	0.966	0.997	0.912	0.829	0.940
	R^2	0.630	0.933	0.994	0.831	0.687	0.883
Three-Ponds							
	R	1.000	1.000	0.971	1.000	0.977	1.000
	R^2	1.000	1.000	0.942	1.000	0.954	1.000

Chapter 5

SUMMARY OF STUDY

This chapter represents a summary of a 5-year study of waste stabilization pond design and performance in tropical areas. The study was conducted from early 1969 through December, 1973, at Fort Clayton in the Canal Zone.

5.1 Objectives of Study

The broad objectives of this research project as delineated in 1969 were as follows:

To investigate and define ---

(1) The roles of physical, chemical, and microbiological parameters in relation to operation of stabilization ponds in tropical areas. Particular emphasis will be placed upon waste material characteristics and loadings, dissolved oxygen, algae type and production, and the influence of temperature and the relatively high intensity sunlight of tropical areas.

(2) The effect of stabilization pond environmental conditions on the viability of certain enterobacterial pathogens.

(3) The effects of various detention periods, water depths, and loading fluctuations upon the operation and performance of stabilization ponds in tropical areas.

(4) Maximum acceptable loading limits, in terms of 5-day, 20°C biochemical oxygen demand (BOD) in relation to design and operating parameters.

Specific sub-objectives added in 1971 and conducted in 1972-73 involved testing a single pond to organic loading failure, and the study of a two-cell pond system. Sub-objectives added in 1972 and accomplished in 1973 included study of a three-cell pond system and conduction of bench-scale experiments on selected health aspects of pond operation. The health-related experiments were directed toward the fate of Salmonella typhi in ponds, the fate and influence of pesticides in ponds, and the dispersion of Escherichia coli in a receiving stream for the pond effluent. The receiving stream for the Fort Clayton ponds was the Panama Canal just downstream from the Miraflores Locks.

5.2 Need for Study

The United States Army has a basic commitment to properly dispose of wastewaters generated at its installations in the continental United States and around the world. The Army has many installations in tropical areas around the world, and since pond systems provide a low-cost wastewater treatment option, this project was oriented to the development of performance data and design criteria for waste stabilization pond systems in tropical applications. In addition to their economic favorability, ponds also have advantages in terms of ease of construction, start-up, operation and maintainance, and shut-down. The unique wastewater treatment requirements at Army installations are summarized in Chapter 1.

5.3. Experimental Program

The field pond study was conducted through the utilization of two pilot waste stabilization ponds. Each of the two ponds had length to width ratios of 2:1 and embankments with horizontal to vertical slopes of 3:1. The berms of the ponds were eight feet above the pond bottoms, and each of the two ponds had a 0.5 acre surface area when operated at a liquid depth of five feet. Wastewater entered the ponds through vertical risers which extended six inches above the bottom of each pond, and were located one-third of the length of the ponds from the influent end. Approximately six feet from the opposite end, the effluent was discharged into a standpipe. The construction of a third pond was accomplished in the spring of 1973. The third pond was an anaerobic pond having a length to width ratio of 3:1, and embankments with horizontal to vertical slopes of 1:1. The berms were twelve feet above the pond bottom and the surface area was 1,716 square feet (0.039 acres) when operated at a six-foot depth.

The experimental program consisted of four major operational phases with specific purposes as follows:

(1) Phase I: To determine whether, for a given wastewater loading, a four- or six-foot liquid depth offered the better

treatment, and to establish a base of reference data to which the data from the subsequent three operational phases could be compared. This phase was conducted from February, 1969, to June, 1971.

(2) Phase II: To determine the optimum wastewater loading for a single-celled pond. This phase was carried out from June, 1971, to August, 1972.

(3) Phase III: To determine whether, for a given wastewater loading, a single-celled or a two-celled pond system offered more advantages. This phase was accomplished from August, 1972, to July, 1973.

(4) Phase IV: To determine if the addition of a small anaerobic pond at the beginning of a two-pond series system would reduce wastewater short-circuiting and allow a greater quantity of solids settling, thereby permitting a substantial increase in bacterial and BOD removals as compared to systems where only facultative ponds were involved. This phase was the focus from July through December, 1973.

5.4. Results of Experimentation Program

Twenty-eight different variables were measured over the 5-year research period. A list of these variables as well as selected means and standard deviations for the pond effluents during experimental phase I is contained in Table 5.1 for the 6-foot single pond, and Table 5.2 for the 4-foot single pond. It should be noted

TABLE 5.1: DATA VARIABILITY FOR THE 6-FT. SINGLE POND EFFLUENT

Variable No.	Variable Name	Mean	Standard Deviation
1	Flow	0.09	0.08
2	BOD_{20}	77.77	12.08
3	BOD_{30}	112.80	12.52
4	Acidity	46.16	6.48
5	Alkalinity	133.09	7.98
6	pH	6.70	0.18
7	DO	1.00	0.24
8	Water temperature	28.97	2.09
9	Total solids	493.11	113.42
10	Volatile solids	234.68	100.79
11	Total phosphate	31.73	4.06
12	Orthophosphate	31.78	3.49
13	Organic nitrogen	18.84	3.65
14	Ammonia	8.57	1.68
15	Nitrate	1.64	0.89
16	Nitrite	1.90	1.05
17	Depth	---	---
18	Phylum algae	---	---
19	Class algae	---	---
20	Genus algae	---	---
21	Species algae	---	---
22	Plankton count	---	---
23	Rainfall	---	---
24	Solar radiation	329.25	135.61
25	Relative humidity max.	1.00	0.01
26	Relative humidity min.	0.61	0.12
27	Air temperature max.	32.43	2.90
28	Air temperature min.	23.11	1.92

TABLE 5.2: DATA VARIABILITY FOR THE 4-FT. SINGLE POND EFFLUENT

Variable No.	Variable Name	Mean	Standard Deviation
1	Flow	0.07	0.10
2	BOD_{20}	75.85	9.84
3	BOD_{30}	109.37	10.30
4	Acidity	45.32	8.02
5	Alkalinity	130.88	9.61
6	pH	6.81	0.30
7	DO	1.48	2.76
8	Water temperature	29.63	1.95
9	Total solids	481.22	133.69
10	Volatile solids	221.80	84.40
11	Total phosphate	31.13	4.03
12	Orthophosphate	30.20	3.57
13	Organic nitrogen	18.31	2.05
14	Ammonia	8.04	2.83
15	Nitrate	1.76	0.70
16	Nitrite	2.23	1.71
17	Depth	---	---
18	Phylum algae	---	---
19	Class algae	---	---
20	Genus algae	---	---
21	Species algae	---	---
22	Plankton count	---	---
23	Rainfall	---	---
24	Solar radiation	321.63	138.39
25	Relative humidity max.	1.00	0.0
26	Relative humidity min.	0.61	0.11
27	Air temperature max	32.10	2.65
28	Air temperature min	22.95	1.86

that most research studies and pond operations have not involved the collection of data for this many variables; in fact, the key variables from this study are flow, BOD_{20}, suspended solids, nitrogen, phosphorus and fecal coliforms.

A summary of the average wastewater loadings on each of the pond systems is shown in Table 5.3. This table also contains a summary of the percentage removals of various parameters in the pond systems. The three-pond system yielded the best overall performance. Also included in Table 5.3 are the average values for the hydraulic ratio factor and the weather factor.

Typical performance values for other treatment processes are summarized from the literature in Table 5.4. The Panama ponds did not yield the degree of treatment that can be accomplished by conventional treatment with activated sludge on trickling filtration. This was as expected from the literature review which is summarized in chapter 2.

A complete discussion of the results of the experimentation program is included in chapter 3 of this report.

5.5. Empirical Design Equations From the Literature

The empirical design equations which have been previously developed include relationships for bacterial and BOD removals in facultative ponds, and BOD removals in anaerobic ponds. The equations are as follows:

TABLE 5.3: OVERALL AVERAGE SYSTEM PERFORMANCE

Pond System	Loadings (lbs/acre/day)				Removal (%)						Ratios	
	BOD	COD	Nitrogen (O+A)	Ortho-phosphate	BOD	COD	Nitrogen (O+A)	Nitrate	Ortho-phosphate	E. coli	(Inf-Eff)/Inf	(Prec-Evap)/Prec
Four-foot Pond	277	496	69	53	63	47	40	-5	-18	76	0.568	-1.249
Five-foot Pond	349	585	119	77	56	41	38	-15	-32	61	0.070	-0.774
Six-foot Pond	231	392	42	33	57	44	44	1.4	-7	83	0.650	-1.252
Two Pond System	201	314	64	42	68	43	47	0.4	-21	55	0.426	-0.774
Three Pond System	142	366	49	33	75	60	58	-18	-32	91	0.483	0.654

TABLE 5.4: LITERATURE VALUES FOR TREATMENT SYSTEM PERFORMANCE

Sewage Treatment Process	% Removal*			
	BOD	COD	Suspended Solids	Bacterial
Fine screening	5-10	5-10	2-20	10-20
Chlorination of raw or settled sewage	15-30	----	----	90-95
Plain sedimentation	25-40	20-35	40-70	25-75
Chemical precipitation	50-85	40-70	70-90	40-80
Trickling filtration preceded and followed by plain sedimentation	50-95	50-80	50-92	90-95
Activated-sludge treatment preceded and followed by plain sedimentation	55-95	50-80	55-95	90-98
Chlorination of biologically treated sewage	----	----	----	98-99
High-rate trickling filter, two stage	80-95			
Sand filtration (intermittent)	90-95		85-95	
Rapid sand filtration	60-85		80-95	

*Sources: Sewerage & Sewage Treatment Table 28-1, and Water Purification & Wastewater Treat. & Disposal Table 21-2.

A. Bacterial Removal (Facultative Ponds)

1. Malina and Yousef (1964)

$$100 - P.R. = \frac{100}{KR + 1}$$

where:

P.R. = percentage removal
K = reaction constant
R = detention time (days)

2. Marais (1966)

Single Pond

$$100 - P.R. = \frac{100}{KR + 1}$$

Two Ponds in Series

$$100 - P.R. = \frac{100}{(KR_1 + 1)(KR_2 + 1)}$$

where:

P.R. = percentage removal
K = 2.0 (Esch. coli)
= 0.8 (S. typhi)
R_1 = detention time (days) in pond 1
R_2 = detention time (days) in pond 2

3. Mauldin (1968)

$$P.R. = \frac{(100)(K')\ R^{0.04}}{L^{0.306}\ D^{0.0033}}$$

$$K' = 0.0089\ L + 2.55$$

where:

K' = proportionality constant
L = organic loading rate (lb. BOD/ac/day)
D = depth (ft.)
R = detention time (days)

B. BOD Removal (Facultative Ponds)

1. Herman and Gloyna (1958)

$$V = 10.7 \times 10^{8}\ Q\ y\ \theta^{(35 - T)}$$

where:

V = waste stabilization pond volume (acre-ft.)
Q = wastewater flow (gal. per day)
y = influent 5-day, 20°C BOD (mg/1)
T = temperature (°C)
θ = temperature coefficient = 1.072

2. Herman and Gloyna (1959)

$$P = 100 - 0.05(L)$$

where:

P = percent decrease in BOD_5
L = loading rate (lb. BOD_5/ac/day)

3. Marais and Shaw (1961)

$$L_p = \frac{600}{0.18\ d + 8}$$

where:

L_p = effluent BOD_5 (mg/1)
d = depth (m.)

4. Englande (1968)

$$P = 93 - 0.02\ (L)$$

where:

P = percent decrease in BOD_5
L = loading rate (lb. BOD_5/ac/day)

5. McGarry and Pescod (1970)

$$L_r = 9.23 + 0.725\ L_a$$

where:

L_r = areal BOD removal (lb./ac/day)
L_a = influent BOD (mg/1)

6. Aguirre and Gloyna (1970)

$$\text{Area} = 3.07 \times 10^{-3}\ Q'S_o\ 1.085^{(35 - T)}\ f \cdot f'$$

where:

Area = surface area (acres)*

Q' = flow (million gallons per day)

S_o = influent BOD_u (mg/l)**

T = average temperature of coldest month (°C)

f = algal toxicity or compensation factor, f = 1 for most domestic wastes

f' = sulfide correction, f' = 1 for SO_4 ion concentrations of less than 500 mg/l or equivalent S.

7. Gloyna (1971)

$$L_p = \frac{L_o}{K_T R_T + 1}$$

*This is based on a depth of 5 feet plus a sludge storage zone of one foot for all primary facultative waste stabilization ponds. The added foot need not be provided if an anaerobic pond preceeds the facultative waste stabilization pond.***

**For domestic wastes containing unusually large amounts of settleable but biodegradable wastes it will be necessary to take special precautions to obtain a true equivalent BOD_u.

***The BOD_5 removal efficiency can be expected to be about 90% as based on unfiltered influent samples and filtered effluent samples. The efficiency of removal based on unfiltered effluent samples can be expected to vary considerably but normally the values will range between 70% and 85%.

where:

L_p = pond and effluent BOD_5 (mg/l)

L_o = influent BOD_5 (mg/l)

K_T = BOD stabilization rate at temperature T, T in °C, and K_T in per day

R_T = detention time at temperature T (days)

8. Siddiqi and Handa (1971)

$$P = \frac{100}{1 + 0.188\, L_f^{0.48}}$$

where:

P = BOD removal efficiency

L_f = load factor which is ratio of BOD loading (lb/ac/day) to oxygen production by algae (lb/ac/day); this equation applies for L_f values between 0.44 and 8.0

C. BOD Removal (Anaerobic Ponds)

1. Vincent (1971)

$$L_p = \frac{L_o}{K_n\left(\frac{L_p}{L_o}\right)^n R + 1}$$

where:

L_p = pond and effluent BOD_5 (mg/l)

L_o = influent BOD_5 (mg/l)

R = detention time for completely mixed system (days)

K_n = design coefficient

n = exponent, for Zambia n = 4.8

5.6. Performance Equations From This Study

The data collected in this study were subjected to multiple regression analysis, and performance equations were developed for each pond system for the percentage removal of BOD, COD, nitrogen, nitrates, orthophosphates and E. coli. The equations are presented in Tables 5.5 through 5.10, respectively. A discussion of the data reduction is contained in chapter 4. The symbols used in Tables 5.5 through 5.10 are as follows:

BOD_L : Biochemical Oxygen Demand Loading

COD_L : Chemical Oxygen Demand Loading

N_L : Organic Nitrogen + Ammonia Loading

P_L : Orthophosphates Loading

$\frac{I-E}{I}$: (Influent Flow-Effluent Flow)/Influent Flow

$\frac{P-E}{P}$: (Precipitation-Evaporation)/Precipitation

N : Organic Nitrogen + Ammonia

P : Orthophosphates

5.7. Conclusions

The following conclusions can be drawn from this study:

(1) Due to nearly ideal weather conditions in terms of temperature, solar radiation, and windspeed, waste stabilization ponds can operate very satisfactorily in tropical areas.

(2) The pond system which yielded the highest effluent quality from this study was a three-pond system consisting of an

TABLE 5.5: BOD REMOVAL EQUATIONS FOR POND SYSTEMS

Four-Foot Pond

$$\% \text{ BOD Removal} = 88.094 - 0.186\ BOD_L + 0.458\ N_L - 0.851\left(\frac{P-E}{P}\right) + 6.920\left(\frac{I-E}{I}\right) - 0.63\ P_L + 0.046\ COD_L$$

Five-Foot Pond

$$\% \text{ BOD Removal} = 90.638 + 0.022\ BOD_L - 0.050\ P_L$$

Six-Foot Pond

$$\% \text{ BOD Removal} = 38.332 - 0.108\ BOD_L + 20.372\left(\frac{I-E}{I}\right) - 0.287\ N_L + 2.506\ P_L - 0.099\ COD_L$$

Two-Pond System

$$\% \text{ BOD Removal} = 19.976 + 105.440\left(\frac{I-E}{I}\right) + 0.074\ COD_L - 0.101\ BOD_L$$

Three-Pond System

$$\% \text{ BOD Removal} = 14.469 + 27.244\left(\frac{P-E}{P}\right) + 73.942\left(\frac{I-E}{I}\right) + 0.071\ BOD_L - 0.160\ N_L - 0.149\ P_L + 0.027\ COD_L$$

TABLE 5.6: COD REMOVAL EQUATIONS FOR POND SYSTEMS

Four-Foot Pond

$$\% \text{ COD Removal} = 2.378 + 56.837\left(\frac{I-E}{I}\right) + 0.101\ COD_L - 0.789\ P_L + 0.056\ N_L$$

Five-Foot Pond

$$\% \text{ COD Removal} = 26.849 + 0.117\ COD_L - 1.523\left(\frac{P-E}{P}\right) - 0.520\ P_L - 0.019\ BOD_L - 64.358\left(\frac{I-E}{I}\right) - 0.036\ N_L$$

Six-Foot Pond

$$\% \text{ COD REmoval} = -47.117 + 0.992\ N_L + 0.152\ BOD_L + 59.106\left(\frac{I-E}{I}\right) + 1.882\left(\frac{P-E}{P}\right) - 0.668\ P_L$$

Two-Pond System

$$\% \text{ COD Removal} = 133.117 + 0.289\ COD_L - 1.633\ P_L - 0.232\ BOD_L + 0.291\ N_L - 208.932\left(\frac{I-E}{I}\right) - 5.440\left(\frac{P-E}{E}\right)$$

Three-Pond System

$$\% \text{ COD Removal} = 45.231 - 0.109\ COD_L - 0.709\ N_L + 34.448\left(\frac{I-E}{I}\right) - 11.766\left(\frac{P-E}{P}\right)$$

TABLE 5.7: NITROGEN REMOVAL EQUATIONS FOR POND SYSTEMS

Four-Foot Pond

$$\% \text{ N Removal} = 59.173 + 0.032\ COD_L + 0.736\left(\frac{P-E}{E}\right) + 2.826\left(\frac{I-E}{I}\right) + 0.492\ N_L - 0.830\ P_L - 0.093\ BOD_L$$

Five-Foot Pond

$$\% \text{ N Removal} = 40.434 - 0.089\ COD_L + 0.207\ N_L + 1.115\left(\frac{P-E}{P}\right) + 0.213\ P_L + 0.027\ BOD_L$$

Six-Foot Pond

$$\% \text{ N Removal} = 313.997 + 0.429\ COD_L - 6.644\ P_L - 0.347\ BOD_L - 133.620\left(\frac{I-E}{I}\right) - 1.385\ N_L - 3.053\left(\frac{P-E}{P}\right)$$

Two-Pond System

$$\% \text{ N Removal} = 14.456 + 0.264\ BOD_L - 1.059\ N_L - 0.491\ N_L + 0.137\ COD_L + 59.575\left(\frac{I-E}{I}\right) + 1.153\left(\frac{P-E}{P}\right)$$

Three-Pond System

$$\% \text{ N Removal} = 11.466 + 87.464\left(\frac{I-E}{I}\right) + 0.272\ P_L - 26.979\left(\frac{P-E}{P}\right) + 0.036\ COD_L$$

TABLE 5.8: NITRATE REMOVALS FOR POND SYSTEMS

Four-Foot Pond

$$\%\ \text{Nitrate Removal} = -\ 5.474 - 0.931\ N_L + 0.181\ BOD_L - 1.432\ P_L - 0.104\ COD_L$$

Five-Foot Pond

$$\%\ \text{Nitrate Removal} = -\ 117.225 + 0.223\ BOD_L - 7.406\left(\frac{P-E}{P}\right) + 0.584\ P_L - 0.227\ N_L$$

Six-Foot Pond

$$\%\ \text{Nitrate Removal} = -\ 54.899 + 0.433\ BOD_L + 1.683\ N_L - 6.269\ P_L + 0.222\ COD_L$$

Two-Pond System

$$\%\ \text{Nitrate Removal} = 549.286 - 32.839\left(\frac{P-E}{P}\right) - 1094.866\left(\frac{I-E}{I}\right) - 1.548\ BOD_L + 0.902\ COD_L - 4.777\ P_L + 1.888\ N_L$$

Three-Pond System

$$\%\ \text{Nitrate Removal} = -\ 42.882 + 157.851\left(\frac{I-E}{I}\right) - 1.060\ P_L - 23.897\left(\frac{P-E}{P}\right) + 0.052\ COD_L - 0.954\ N_L + 0.189\ BOD_L$$

TABLE 5.9: ORTHOPHOSPHATE REMOVALS FOR POND SYSTEMS

Four-Foot Pond

$$\%\ P\ \text{Removal} = 43.553 - 0.556\ N_L - 62.614\left(\frac{I-E}{I}\right) + 0.025\ COD_L$$

Five-Foot Pond

$$\%\ P\ \text{Removal} = -\ 79.345 + 0.886\ N_L - 197.609\left(\frac{I-E}{I}\right) + 3.423\left(\frac{P-E}{P}\right)$$
$$-\ 0.014\ BOD_L + 1.397\ P_L - 0.248\ COD_L$$

Six-Foot Pond

$$\%\ P\ \text{Removal} = 29.625 + 0.082\ COD_L + 0.303\left(\frac{P-E}{P}\right) - 19.005\left(\frac{I-E}{I}\right)$$
$$-\ 0.099\ BOD_L - 0.416\ N_L - 0.474\ P_L$$

Two-Pond System

$$\%\ P\ \text{Removal} = -\ 79.973 - 0.548\left(\frac{P-E}{P}\right) + 114.290\left(\frac{I-E}{I}\right) - 0.413\ COD_L$$
$$+\ 3.332\ P_L$$

Three-Pond System

$$\%\ P\ \text{Removal} = -\ 293.396 + 4.921\ P_L + 326.894\left(\frac{I-E}{I}\right) - 2.962\ N_L$$
$$+\ 0.229\ COD_L$$

TABLE 5.10: E. COLI REMOVALS FOR POND SYSTEMS

Four-Foot Pond

$$\%\ \underline{E.}\ \underline{coli}\ \text{Removal} = -20.202 - 0.129\ COD_L - 0.379\ N_L + 107.994\left(\frac{I-E}{I}\right) + 0.244\ BOD_L + 1.078\ P_L$$

Five-Foot Pond

$$\%\ \underline{E.}\ \underline{coli}\ \text{Removal} = 114.798 - 1411.879\left(\frac{I-E}{I}\right) + 15.744\left(\frac{P-E}{P}\right) - 0.014\ BOD_L + 0.356\ COD_L - 1.848\ P_L - 0.047\ N_L$$

Six-Foot Pond

$$\%\ \underline{E.}\ \underline{coli}\ \text{Removal} = 52.546 + 140.600\left(\frac{I-E}{I}\right) + 0.334\ COD_L - 5.875\ P_L$$

Two-Pond System

$$\%\ \underline{E.}\ \underline{coli}\ \text{Removal} = 620.706 + 1.572\ N_L + 1.338\ BOD_L - 0.464\ COD_L - 40.550\left(\frac{P-E}{P}\right) - 1367.918\left(\frac{I-E}{I}\right) - 5.715\ P_L$$

Three- Pond System

$$\%\ \underline{E.}\ \underline{coli}\ \text{Removal} = -85.264 + 122.170\left(\frac{P-E}{P}\right) + 194.613\left(\frac{I-E}{I}\right) + 0.969\ N_L - 0.586\ P_L - 0.069\ COD_L$$

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anaerobic pond followed by a facultative and maturation pond. The three-pond system performed better than either a two-cell system (facultative and maturation pond) or a one-cell system.

(3) It is felt that after extensive study, the design organic loading rate for three-pond systems in tropical areas should not exceed 150 lb. BOD/acre/day. The facultative and maturation pond depths should be between 4 ft. and 6 ft., and the anaerobic pond depth can range up to 12 ft.

(4) Extensive studies of the health-aspects of pond effluents in terms of bacterial removals and the presence of pathogens indicated that no significant health-related effects of pond effluents should occur if the system is properly designed, operated and maintained.

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APPENDIX I

Meteorological Data For 5-Year Period
From January 1969 - December 1973

APP. I: 1. PRECIPITATION (TOTAL INCHES)

Month	Year 1969	1970	1971	1972	1973	5-Year Average
January	1.88		3.99	9.38	.00	3.81
February	.53		1.01	.38	.01	.48
March			.51	1.67	.72	.97
April			3.56	10.72	3.27	5.85
May	7.44	12.74	8.57	7.71	7.44	8.78
June	8.70	7.12	7.41	15.01	12.38	10.12
July	6.27	6.26	9.61	3.60	8.66	6.88
August		9.31	11.80	6.03	4.90	8.01
September		9.92	8.47	10.80	10.99	10.05
October		8.51	12.40	7.87	16.53	11.33
November		12.02	11.71	8.13	12.99	11.21
December		7.85	.37	4.54	6.75	4.88

APP. I: 2. SOLAR RADIATION (LANGLEYS/DAY) VERTICAL EPPLEY

Month	Year 1969	1970	1971	1972	1973	5-Year Average
January	434			383	455	424
February			440	518	486	481
March			423	521	460	468
April	398		453	418	463	433
May	398	375	345	372	366	371
June	323	326	315	365	302	326
July	318	331	299	375	377	340
August		324	316	352	356	337
September		335	337	346	329	337
October		321	356	339	364	345
November		288	324	357	277	312
December		274	385	385	372	354

APP. I: 3. RELATIVE HUMIDITY (%)

Date	Daily Avg. Max	Daily Avg. Min	Monthly Average
January 1969	100	50	82
February	100	47	79
March	100	47	80
April	100	53	84
May	100	58	86
June	98	60	86
July	99	65	89
August			
September			
October			
November			
December			
January 1970			
February			
March			
April			
May	100	74	93
June	97	71	91
July	100	71	91
August	100	73	94
September	100	70	93
October	100	75	95
November	100	78	95
December	100	80	96
January 1971	99	62	89
February	99	51	83
March	99	48	80
April	100	49	80

APP. I: 3. (continue)

Date	Daily Avg. Max	Daily Avg. Min	Monthly Average
May 1971	99	68	90
June			
July			
August	99	67	90
September	100	66	88
October	99	66	89
November	98	64	88
December	96	51	79
January 1972	96	55	81
February	96	46	75
March	98	38	73
April	97	53	82
May	95	54	81
June	98	72	89
July	96	69	87
August	96	70	87
September	96	70	89
October	98	69	89
November	98	65	87
December	96	59	82
January 1973	94	52	77
February	93	47	73
March	94	48	74
April	93	48	74
May	97	64	85
June	95	69	86

APP. I: 3. (continue)

Date	Daily Avg. Max	Daily Avg. Min	Monthly Average
July 1973	97	69	87
August	100	69	90
September	100	70	90
October	98	70	89
November	96	68	
December	97	56	

Month	5-Year Daily Avg. Max	5-Year Daily Avg. Min	5-Year Monthly Average
January	97	55	82
February	97	48	77
March	98	46	76
April	98	51	80
May	98	64	81
June	97	68	88
July	98	69	89
August	99	70	90
September	99	69	90
October	99	70	90
November	98	69	90
December	97	61	86

APP. I: 4. AMBIENT AIR TEMPERATURE (^{o}F)

Date	Daily Avg. Max	Daily Avg. Min	Monthly Average
January 1969	91	75	81
February	90	71	79
March	91	75	83
April	92	76	82
May	92	78	83
June	90	80	84
July	91	76	81
August			
September			
October			
November			
December			
January 1970			
February			
March			
April			
May	90	77	82
June	92	73	79
July	87	71	77
August	88	70	77
September	87	69	75
October	84	68	74
November	82	67	73
December	83	69	74
Janaury 1971	88	70	77
February	94	68	78

APP. I: 4. (continue)

Date	Daily Avg. Max	Daily Avg. Min	Monthly Average
March 1971	94	69	79
April	93	69	79
May	88	72	78
June	89	71	78
July	90	72	78
August	85	75	79
September	84	74	79
October	85	75	79
November	85	75	79
December	87	73	79
January 1972	86	74	79
February	89	74	80
March	89	72	79
April	87	73	78
May	86	74	78
June	89	77	82
July	91	75	81
August	89	76	81
September	90	77	81
October	88	76	80
November	89	76	81
December	90	75	81
January 1973	92	76	82
February	93	74	82
March	95	76	84
April	93	76	83
May	90	78	83

APP. I: 4. (continue)

Date	Daily Avg. Max	Daily Avg. Min	Monthly Average
June 1973	86	76	80
July	88	78	82
August	88	76	81
September	88	77	81
October	86	76	80
November	85	75	
December	88	73	

Month	5-Year Daily Avg. Max	5-Year Daily Avg. Min	5-Year Monthly Average
January	89	74	79
February	92	72	80
March	92	73	81
April	91	73	80
May	89	76	81
June	89	75	81
July	89	74	80
August	88	74	80
September	87	74	79
October	86	74	78
November	85	73	78
December	87	73	78

APP. I: 5. WIND SPEED (MILES/HOUR) & WIND DIRECTION (SIXTEEN POINTS WITH REFERENCE TO TRUE NORTH

Date	Prevailing Direction	Avg. Hourly Speed	Maximum	
			Concurrent & Direction	Hourly Speed
January 1969				
February				
March				
April				
May	NW	4	WNW	18
June	S	3	WNW	13
July	NW	2	MW	7
August				
September				
October				
November				
December				
January 1970				
February				
March				
April				
May				
June	NNW	4	NE	18
July	S	4	S	10
August				
September				
October				
November	NW	1	SW	6
December	NW	1	NW	6

APP. I: 5. (continue)

Date	Prevailing Direction	Avg. Hourly Speed	Maximum Concurrent Direction	& Hourly Speed
January 1971	N	1	N	7
February	NNW	2	NNE	7
March	N	2	NW	6
April	N	2	NW	11
May	NNW	2	NW	11
June	NW	2	NW	9
July	NW	1	NW	7
August	NW	1	NW	4
September	S	1	S	6
October	S	0	S	5
November	NW	0	NW	5
December		2	NNE	9
January	NNW	2	N	11
February	NNW	3	NW	12
March	NNW	3	NNE	11
April	NNW	2	NNW	8
May	NW	2	NNW	6
June				
July				
August	NW	2	NW	7
September	NW	1	NNW	5
October	NW	1	SSE	7
November				
December	N	1	SSW	5

APP. I: 5. (continue)

Date	Prevailing Direction	Avg. Hourly Speed	Maximum Concurrent Direction	Maximum Hourly Speed
January 1973	NNW	2	WNW	6
February				
March			WNW	12
April	NW	3	WNW	13
May	NNW	2	NW	12
June	NW	2	NE	8
July		0	WNW	7
August		3		8
September	S	2	SSE	8
October	S	2	S	9
November				
December				

Month	5-Year Avg. Prevailing Wind Direction	5-Year Avg. Hourly Speed	5-Year Avg. Maximum Concurrent Direction	5-Year Avg. Maximum Hourly Speed
January	NNW	2	N	8
February	NNW	2	NW	9
March	NNW	2	WNW	10
April	NNW	2	WNW	11
May	NW	3	NW	12
June	NW	3	NE	12
July	NW	2	NW	8
August	NW	2	NW	6
September	S	1	SSE	7

APP. I: 5. (continue)

Month	5-Year Avg. Prevailing Wind Direction	5-Year Avg. Hourly Speed	5-Year Avg. Maximum Hourly Speed	& Concurrent Direction
October	S	1	6	S
November	NW	1	6	SW
December	NW	1	7	NNE

APP. I: 6. EVAPORATION (INCHES/MONTH) AT MADDEN LAKE

Month	MD	Month	MD
January 1969	5.132	January 1971	4.406
February	5.996	February	6.044
March	6.403	March	6.369
April	5.774	April	7.004
May	3.946	May	3.151
June	2.779	June	2.762
July	2.664	July	3.039
August	2.465	August	2.873
September	2.593	September	2.930
October	3.674	October	3.251
November	2.549	November	2.458
December	3.417	December	5.537
January 1970	4.574	January 1972	4.220
February	5.383	February	5.823
March	5.887	March	7.180
April	5.315	April	4.793
May	3.751	May	4.333
June	3.864	June	3.442
July	3.134	July	5.273
August	2.619	August	3.814
September	2.964	September	2.745
October	2.584	October	2.658
November	2.541	November	5.264
December	2.387	December	4,934

APP. I: 6. (continue)

Month	MD
January 1973	5.927
February	6.224
March	6.989
April	6.751
May	4.816
June	2.369
July	2.617
August	3.222
September	1.196
October	2.694
November	2.710
December	4.297

APPENDIX II

Four-Foot Pond

APP. II: 1. INFLUENT FLOWS (gal/day), BOD (mg/l & lbs/acre/day) AND DT (days)

POND 2

Date	Influent Flow $X10^3$ gal/day	Influent BOD mg/l	Influent BOD lb/acre/day	Theoretical DT days
May '69	153.5	172	551	2.9
June	128.5	115	309	3.5
July	99.6	138	286	4.5
Aug	90.7	152	325	4.9
Sept	86.4	158	285	5.2
Oct	55.9	168	196	8.0
Nov	126.7	146	386	3.5
Dec	102.3	154	229	4.4
Jan '70	84.5	186	228	5.3
Feb	74.6	158	246	6.0
Mar	78.1	170	277	5.7
Apr	72.2	154	232	6.2
May	82.1	158	270	5.4
June	52.6	136	149	8.5
July	56.4	187	220	7.9
Aug	105.1	168	369	4.3
Sept	66.2	166	229	6.7
Oct	88.3	166	306	5.1
Nov	67.2	200	280	6.6
Dec	57.2	189	225	7.8

APP. II: 1. (continue)

POND 2

Date	Influent Flow X10^3 gal/day	Influent BOD mg/l	Influent BOD lb/acre/day	Theoretical DT days
Jan '71	57.3	156	186	7.8
Feb	58.4	226	275	7.6
Mar	86.6	200	361	5.2
Apr	77.6	181	292	5.8
May	56.8	238	282	7.9
June	54.7	214	244	8.2
				Ponds 2 & 1
July	41.2*	184	157	10.8*
Aug	39.6	180	149	11.3
Sept	63.8	191	254	7.0
Oct	68.4	197	281	6.5
Nov	61.2	188	240	7.3
Dec	44.0	212	195	10.2
Jan 1-15 '72	58.0	272	329	7.7
Average	75.6	179	274	6.5

*Note: The flows to ponds 1and 2 during the time were the same, the influent BOD concentrations were also assumed to be equal for the two ponds and therefore the DT are the same for both ponds.

APP. II: 1. (continue)

POND 2

Date	Influent Flow X10^3 gal/day	Influent BOD mg/l	Influent BOD lb/acre/day	Theoretical DT days
January 16-31 '72	27.4	186	106	16.3
Feb	25.7	208	111	17.4
Mar	42.5	189	167	10.5
Apr	55.2	176	202	8.1
May	82.0	164	280	5.4
June	91.7	142	271	4.9
July	49.7	143	149	9.0
Aug 1-15	58.0	129	156	7.7
Avgerage	54.0	167	180	9.9

POND 1

Date	Influent Flow X10^3 gal/day	Influent BOD mg/l	Influent BOD lb/acre/day	Theoretical DT days
January 16-31 '72	45.5	186	176	9.8
Feb	64.2	208	279	7.0
Mar	116.0	189	457	3.8
Apr	150.1	176	551	3.0
May	228.7	164	328	2.0
June	250.0	142	740	1.8
July	211.5	143	631	2.1
Aug 1-15	207.9	129	560	2.1
Average	159.2	167	522	3.9

APP. II: 2. BOD REMOVALS (%)

POND 2

Date	Effluent BOD mg/1	% mg BOD/1 Removal
May '69	101	42
June	71	39
July	71	49
Aug	66	62
Sept	66	59
Oct	66	61
Nov	69	53
Dec	80	48
Jan '70	77	59
Feb	82	49
Mar	66	62
Apr	63	60
May	61	62
June	49	64
July	69	64
Aug	69	59
Sept	53	69
Oct	60	64
Nov	68	66
Dec	69	64
Jan '71	76	52
Feb	89	61
Mar	103	49

APP. II: 2. (continue)

POND 2

Date	Effluent BOD mg/1	% mg BOD/1 Removal
Apr '71	112	39
May	108	55
June	101	53
July	56	70
Aug	44	76
Sept	54	72
Oct	64	68
Nov	36	81
Dec	56	74
Jan 1-15 '72	64	77
Average	71	60
Jan 16-31 '72	46	76
Feb	56	74
Mar	55	71
Apr	66	63
May	58	65
June	42	71
July	58	60
Aug	58	56
Average	55	67
Total Average	68	61

APP. II: 2. (continue)

POND 1

Date	Effluent BOD mg/l	% BOD Removal
July '71	63	66
Aug	55	70
Sept	49	75
Oct	67	66
Nov	51	73
Dec	59	73
Jan 1-15 '72	49	82
Average	56	72
Jan 16-31 '72	63	67
Feb	34	84
Mar	75	61
Apr	74	58
May	85	49
June	74	48
July	107	36
Aug	83	36
Average	66	63
Total Average	62	67

APP. II: 3. COD REMOVALS (%)

Date	Eff COD (mg/l)	% Removal
May '70	218	66
June	---	--
July	---	--
Aug	259	--
Sept	179	36
Oct	184	53
Nov	220	13
Dec	---	--
Jan '71	168	38
Feb	---	--
Mar	194	32
Apr	283	20
May	204	27
June	218	22
July	141	58
Aug	141	42
Sept	118	69
Oct	110	53
Nov	120	57
Dec	114	48
Jan '72	150	28
Average	177	39
Feb '72	180	62
Mar	239	47
Apr	189	70

APP. II: 3. (continue)

POND 2

Date	Eff COD (mg/l)	% Removal
May '72	127	66
June	104	45
July	148	29
Aug	176	*
Average	166	53
Total Average	172	42

POND 1

July '71	148	55
Aug	83	66
Sept	194	49
Oct	111	53
Nov	114	59
Dec	166	24
Jan '72	133	37
Average	136	49
Feb '72	158	67
Mar	180	60
Apr	155	75
May	132	65
June	104	45
July	148	29
Aug	124	29
Average	146	62
Total Average	139	54

*Month of conversion to two ponds in series.

APP. II: 4. SOLIDS REMOVAL (%)

POND 2

Date	Total Solids		Volatile Solids	
	Eff Conc (mg/l)	% Removal	Eff Conc (mg/l)	% Removal
June '70	514	- 4	212	12
July	756	-20	306	5
Aug	541	-24	234	- 9
Sept	474	6	220	- 8
Oct	504	2	245	- 9
Nov	486	- 3	234	- 9
Dec	492	1	228	- 5
Jan '71	---	---	---	--
Feb	590	2	276	10
Mar	485	4	230	- 5
Apr	520	0	221	59
May	567	-18	212	- 1
June	852	23	373	- 7
July	602	7	230	3
Aug	696	-14	218	34
Sept	494	-36	212	1
Oct	720	-40	284	-18
Nov	215	66	52	85
Dec	542	10	214	33

No Data for CY '72

APP. II: 4. (continue)

POND 1

Date	Total Solids		Volatile Solids	
	Eff Conc (mg/l)	% Removal	Eff Conc (mg/l)	% Removal
July '71	584	10	252	- 7
Aug	680	-11	242	27
Sept	486	-34	230	- 7
Oct	704	-36	322	-34
Nov	498	22	200	40
Dec	641	- 7	240	25

No Data for CY '72

APP. II: 5. ACIDITY AND ALKALINITY REMOVALS (%)

POND 2

Date	Acidity		Alkalinity	
	Eff Conc*	% Removal	Eff Conc*	% Removal
June '70	36	25	114	2
July	38	24	112	- 6
Aug	32	38	118	- 2
Sept	28	44	112	3
Oct	36	22	128	0
Nov	32	27	148	-14
Dec	28	42	160	-27
Jan '71	--	--	---	---
Feb	50	29	126	-21
Mar	54	- 8	140	- 9
Apr	54	-13	137	- 4
May	57	-19	134	- 5
June	47	10	134	1
July	46	21	152	-27
Aug	28	58	156	-34
Sept	42	12	140	- 9
Oct	56	-12	138	- 6
Nov	52	13	142	-27
Dec	44	27	120	- 3
Jan '72	Discontinued		---	---
Feb	"		174	---
Mar	"		105	- 5
Apr	"		120	-26
May	"		135	10
June	"		116	23
July	"		142	6
Aug	"		114	---

*Effluent concentrations are in mg/l.

APP. II: 5. (continue)

POND 1

Date	Acidity		Alkalinity	
	Eff Conc*	% Removal	Eff Conc*	% Removal
July '71	48	17	148	-23
Aug	30	55	164	-41
Sept	38	21	142	-11
Oct	48	4	128	2
Nov	56	7	140	-25
Dec	30	50	156	-34
Jan '72	Discontinued		----	----
Feb	"		198	----
Mar	"		162	-62
Apr	"		128	-35
May	"		145	3
Jun	"		170	-13
Jul	"		171	-13
Aug	"		148	---

*Effluent concentrations are in mg/l.

APP. II: 6. NITROGEN REMOVALS (%)

POND 2

Date	Organic		Ammonia		Nitrate		Nitrite	
	Conc*	% Rem	Conc*	% Rem	Conc*	% Rem	Conc*	% Rem
June '70	12.84	26	1.9	80	.20	17	.0038	-660
July	14.43	35	4.5	63	.14	0	.0040	-700
Aug	17.11	15	9.5	12	.12	0	.0053	- 39
Sept	13.01	53	3.6	74	.13	32	.0110	-( )
Oct	15.72	30	7.5	59	.12	8	.0000	0
Nov	19.81	42	9.2	75	.13	--	.0000	0
Dec	-----	--	---	--	---	--	-----	----
Jan '71	19.56	--	7.21	17	.12	20	.0000	0
Feb	18.99	28	7.2	51	.15	12	.0020	-( )
Mar	22.45	18	8.7	16	.15	22	.0010	-( )
Apr	21.98	49	6.8	66	.18	38	.0000	0
May	21.32	46	11.3	47	.24	-33	.0000	0
June	-----	--	---	--	.26	-44	-----	----
July	18.55	--	7.0	--	.19	46	.0000	0
Aug	-----	--	---	--	.14	18	-----	----
Sept	-----	--	9.1	- 3	.14	50	.0020	-( )
Oct	14.10	62	6.2	69	.13	35	.0005	0
Nov	13.79	66	---	--	.18	-13	-----	----
Dec	16.80	63	8.5	61	.17	-42	.0005	-( )
Jan '72	15.82	23	7.5	40	.13	-30	-----	----
Feb	14.56	66	7.0	56	.16	31	.0000	----
Mar	22.77	16	6.5	49	.15	43	.0000	0
Apr	22.49	13	11.2	25	.18	6	.0000	0
May	15.54	--	12.4	--	.19	-27	-----	----
June	11.25	57	8.2	-56	.17	-31	-----	----

*Effluent concentration in mg/1.

APP. II: 6. (continue)

POND 2

Date	Organic Conc*	Organic % Rem	Ammonia Conc*	Ammonia % Rem	Nitrate Conc*	Nitrate % Rem	Nitrite Conc*	Nitrite % Rem
July '72	16.23	47	3.8	81	.08	33	-----	----
Aug	16.24	38	7.5	50	.11	-10	-----	----

POND 1

Date	Organic Conc*	Organic % Rem	Ammonia Conc*	Ammonia % Rem	Nitrate Conc*	Nitrate % Rem	Nitrite Conc*	Nitrite % Rem
July '71	16.55	--	10.9	--	.25	43	.0000	----
Aug	-----	--	9.4	--	.14	18	-----	----
Sept	-----	--	7.5	15	.24	14	.0010	-( )
Oct	15.39	59	8.2	59	.31	-55	.0000	100
Nov	13.77	66	6.0	72	.14	12	-----	----
Dec	17.43	62	8.6	61	.20	-67	-----	0
Jan '72	16.24	21	10.0	20	.10	0	.0000	----
Feb	20.44	52	12.6	21	.20	14	.0000	----
Mar	21.93	19	11.6	9	.17	35	.0000	0
Apr	18.76	28	10.6	29	.18	6	.0000	0
May	16.73	--	7.2	--	.16	- 7	Stopped	Running
June	13.53	49	9.2	--	.12	8	"	
July	23.75	23	10.4	46	.13	- 8	"	
Aug	-----	--	---	--	.09	10	"	

*Effluent concentration in mg/l.

APP. II: 7. PHOSPHATE REMOVALS (%)

POND 2

Date	Total Phosphate		Orthophosphate	
	Conc*	% Rem	Conc*	% Rem
June '70	32.1	4	31.7	3
July	29.6	9	28.4	10
Aug	26.6	- 4	26.1	- 5
Sept	23.5	---	20.4	---
Oct	24.0	---	21.7	---
Nov	-----	---	-----	---
Dec	-----	---	-----	---
Jan '71	28.3	4	27.8	0
Feb	30.7	-12	30.4	-11
Mar	34.5	-25	34.0	-28
Apr	38.4	-41	36.9	-65
May	Discontinued Running		25.0	---
NO DATA BETWEEN MAY '71 AND APR '72				
Apr '72		"	14.6	12
May		"	20.6	2
June		"	28.0	12
July		"	41.9	-67
Aug		"	45.2	-48

*Effluent concentration in mg/l.

APP. II: 7. (continue)

POND 1

Date	Total Phosphate		Orthophosphate	
	Conc*	% Rem	Conc*	% Rem
Apr '72	---	---	17.6	- 6
May	---	---	22.8	- 9
June	---	---	36.6	-15
July	---	---	49.7	-98
Aug	---	---	44.9	-47

*Effluent concentration in mg/l.

APP. II: 8. BACTERIAL GROUPS (COUNTS/ml)

Feb. 19/69 - Dec. 30/70

37°C Bacterial Group	Number of Samples with Indicated Counts/ml $<10^2$	10^2	10^3	10^4	10^5	$>10^5$
Enterobacter						
Inf	21	9	23	27	9	1
Eff 2	41	18	20	9	3	2
Alcaligenes						
Inf	16	13	23	23	15	0
Eff 2	13	22	22	30	5	1
Escherichia						
Inf	0	0	5	31	40	9
Eff 2	1	0	34	40	17	1
Klebsiella						
Inf	18	8	27	30	6	1
Eff 2	66	11	12	7	1	—
Pseudomonas						
Inf	40	14	18	17	1	0
Eff 2	30	18	29	13	2	1
Proteus						
Inf	20	6	23	31	9	1
Eff 2	52	13	21	5	0	2
Intermediate Coliforms						
Inf	2	11	41	27	8	1
Eff 2	5	17	61	7	3	0
Providence						
Inf	46	13	23	8	0	0
Eff 2	52	12	18	1	0	0

APP. II: 9. TOTAL COLONY COUNTS (ORGANISMS/ml)

Total Plate Count		Number of Samples with Indicated Counts/ml					
		$<10^4$	10^4	10^5	10^6	10^7	$>10^7$
Mar 5/69 - June 1971							
25°C	Inf	--	--	19	85	9	--
	Eff 2	--	4	76	33	4	--
June 25/69 - June 1971							
37°C	Inf	--	--	1	20	78	--
	Eff 2	--	--	4	38	57	--

APP. II: 9a. TOTAL COLONY COUNTS (ORGANISMS/ml)

July 1971 - Jan 15/72

25°C	Inf	--	--	1	15	8	--
	Eff 1	--	1	8	11	4	--
	Eff 2	--	1	7	15	1	
37°C	Inf	--	--	--	6	18	--
	Eff 1	--	--	3	9	12	--
	Eff 2	--	--	2	8	14	--

APP. II: 9b. TOTAL COLONY COUNTS (ORGANISMS/ml)

Jan 15/72 - Aug 16/72

25°C	Inf	--	1	6	20	3	--
	Eff 1	--	5	19	6	--	--
	Eff 2	--	2	23	4	--	--
37°C	Inf	--	--	1	13	16	--
	Eff 1	--	--	9	20	1	--
	Eff 2	--	--	6	19	4	--

APP. II: 10. TOTAL COLONY REMOVAL (%)

Feb 19/69 - Jun 30/71

Total Plate Count		Number of Samples with Indicated % Removals						
		<0	0-20	21-40	41-60	61-80	81-90	>90
25°C	Pond 2	9	3	8	20	35	23	14
37°C	Pond 2	23	21	21	15	21	11	2

APP. II: 10a. TOTAL COLONY REMOVAL (%)

Jul 1/71 - Jan 15/72

25°C	Pond 1	3	1	2	2	8	5	3
	Pond 2	1	2	3	3	3	8	4
37°C	Pond 1	4	4	3	1	7	4	1
	Pond 2	1	6	1	4	9	2	1

APP. II: 10b. TOTAL COLONY REMOVAL (%)

25°C	Pond 1	--	2	2	1	11	9	5
	Pond 2	2	--	1	1	9	9	7
37°C	Pond 1	1	1	1	3	8	12	4
	Pond 2	4	--	2	3	10	8	2

APPENDIX III

Five-Foot Pond

APP. III: 1. INFLUENT FLOW (gal/day), BOD (mg/l & lbs/acre/day), AND DT (days)

Month	Influent Flow $X10^3$ gal/day	Influent Flow mg/l	Influent Flow lb/acre/day	Theoretical DT days
Sept '72	133.9	142	317	4.4
Oct	152.1	104	264	3.9
Nov	268.1	102	456	2.2
Dec	237.7	151	599	2.5
Jan '73	130.7	157	243	4.5
Feb	79.9	176	235	7.3
Mar	106.6	173	308	5.5
Apr	131.2	152	333	4.5
May	109.0	145	264	5.4
June	179.7	104	312	3.3
July 1-18	115.2	185	355	5.1
Average	149.5	145	344	4.4

APP. III: 2. BOD REMOVAL (%)

Month	Eff Conc (mg/l)	% Removal (mg/l)
Sept '72	51	65
Oct	50	52
Nov	70	32
Dec	70	54
Jan '73	62	61
Feb	55	69
Mar	50	72
Apr	67	56
May	70	52
June	63	40
July	46	76
Average	60	57

APP. III: 3. COD REMOVAL (%)

Month	Eff (mg/l)	% Removal
Sept '72	142	36
Oct	142	29
Nov	103	34
Dec	103	62
Jan '73	126	32
Feb	124	48
Mar	150	36
Apr	139	42
May	124	36
June	92	41
July	117	45
Average	124	40

APP. III: 4. SOLIDS REMOVALS (%)

Month	Total		Suspended	
	Eff*	Removal	Eff*	% Removal
Sept '72	---	---	.554	60
Oct	---	---	.708	66
Nov	---	---	.927	48
Dec	---	---	2.184	27
Jan '73	---	---	1.034	47
Feb	381	28	.155	58
Mar	---	---	.732	50
Apr	338	23	.963	45
May	388	42	.725	57
June	518	-33	.805	37
July	372	17	.877	44
Average	399	17	.897	49

*Effluent concentration in mg/l.

APP. III: 5. ALKALINITY REMOVALS (%)

Date	Eff Conc*	% Removal
Sept '72	163	- 5
Oct	146	10
Nov	145	5
Dec	141	9
Jan '73	140	0
Feb	129	15
Mar	143	---
Apr	137	17
May	146	4
June	143	2

*Effluent concentrations in mg/l.

APP. III: 6. NITROGEN REMOVALS (%)

Month	Organic Nitrogen		Ammonia		Nitrate	
	Eff*	% Rem	Eff*	% Rem	Eff*	% Rem
Sept '72	19.10	42	12.5	--	.07	30
Oct	25.56	25	12.6	42	.09	-29
Nov	-----	--	----	--	.13	0
Dec	16.51	--	----	--	.10	24
Jan '73	18.06	51	10.1	61	.10	-43
Feb	19.38	54	10.1	62	.08	73
Mar	18.97	--	7.9	10	.23	18
Apr	19.32	24	9.2	37	.18	31
May	17.93	48	9.4	--	.22	-69
June	15.05	--	7.8	54	.10	-100
July	17.94	11	5.4	60	.11	-22
Average	18.78	36	9.4	47	.13	1

*Effluent concentrations in mg/l.

APP. III: 7. ORTHOPHOSPHATE REMOVALS (%)

Month	Eff (mg/l)	% Removal
Sept '72	45.5	-76
Oct	40.3	4
Nov	37.7	-24
Dec	40.7	-23
Jan '73	24.4	-15
Feb	44.3	-56
Mar	42.6	- 3
Apr	39.1	-13
May	21.3	12
June	12.8	15
July	29.8	-102

APP. III: 8. TOTAL COLONY COUNT (ORGANISM/ml)

37°C Total Plate Count	Number of Samples with Indicated Counts/ml					
	$<10^4$	10^4	10^5	10^6	10^7	$>10^7$
Inf	--	--	--	19	17	--
Eff 2	--	--	--	26	10	--

APP. III: 9. COLIFORM COUNTS (ORGANISMS/ml)

Sept. 1972 - July 18/73

37°C Coliform Gourp	Number of Samples with Indicated Counts/ml					
	$<10^2$	10^2	10^3	10^4	10^5	$>10^5$
Total Coliforms						
Inf 2	1	1	--	7	26	3
Eff 2	5	3	11	16	3	--
Fecal Coliforms						
Inf 2	2	1	9	11	15	--
Eff 2	10	9	11	8	--	--
Escherichia Coliforms						
Inf 2	19	2	8	4	5	--
Eff 2	23	1	8	6	--	--

APP. III: 10. TOTAL COLONY REMOVALS (%)

37°C Total Plate Count	Number of Samples with Indicated % Removals <0	0-20	21-40	41-60	61-80	81-90	>90
Pond 2	7	5	6	4	12	7	1

APP. III: 11. COLIFORM REMOVALS (%)

Sept. 20/72 - July 18/73

37°C Total Plate Count	Number of Samples with Indicated % Removals <0	0-39	40-59	60-79	80-89	90-99	>99
Total Coliforms							
Pond 2	3	1	2	5	4	13	9
Fecal Coliforms							
Pond 2	4	2	--	--	3	15	11
E. coli							
Pond 2	6	2	--	--	1	7	5

APPENDIX IV

Six-Foot Pond

APP. IV: 1. INFLUENT FLOW (gal/day), BOD (mg/l & lbs/acre/day), AND DT (days)

Month	Influent Flow $X10^3$ gal/day	Influent BOD mg/l	Influent BOD lb/acre/day	Theoretical DT days
May '69	153.5	172	441	4.8
June	128.5	115	247	5.8
July	99.6	138	229	7.4
Aug	90.7	152	260	8.1
Sept	86.4	158	228	8.6
Oct	55.9	168	157	13.2
Nov	126.7	146	309	5.8
Dec	102.3	154	263	7.2
Jan '70	84.5	186	262	8.7
Feb	74.6	158	197	9.9
Mar	78.1	170	222	9.4
Apr	72.2	154	186	10.2
May	82.1	158	216	8.9
June	52.6	136	119	14.0
July	56.4	187	176	13.0
Aug	105.1	168	295	7.1
Sept	66.2	166	183	11.0
Oct	88.3	166	245	8.4
Nov	67.2	200	224	10.9
Dec	57.2	189	180	12.8
Jan '71	57.3	156	149	12.8
Feb	58.4	226	220	12.5
Mar	86.6	200	289	8.6
Average	84.4	166	230	9.5

APP. IV: 2. BOD REMOVAL (%)

Date	Effluent BOD mg/l	Effluent BOD lb/acre/day	% BOD Removal
May '69	96	--	45
June	69	--	40
July	84	--	40
Aug	55	--	69
Sept	--	--	57
Oct	67	--	61
Nov	70	--	53
Dec	74	--	52
Jan '70	76	--	60
Feb	78	--	51
Mar	86	--	50
Apr	72	--	54
May	73	--	54
June	58	--	58
July	69	--	64
Aug	72	--	58
Sept	62	--	63
Oct	63	--	63
Nov	64	--	68
Dec	64	--	67
Jan '71	65	--	59
Feb	92	--	60
Mar	82	--	59
Average	72	--	57

APP. IV: 3. COD REMOVAL (%)

Month	Eff Conc (mg/l)	% Removal
May '70	314	51
June	----	--
July	422	16
Aug	226	--
Sept	170	39
Oct	183	53
Nov	----	----
Dec	----	--
Jan '71	175	35
Feb	----	--
Mar	160	44
Average	205*	44*

*Data for July '70 was not used in average.

APP. IV: 4. SOLID REMOVALS (%)

Month	Total Solids		Volatile Solids	
	Eff Conc*	% Rem	Eff Conc*	% Rem
June '70	524	- 6	261	- 9
July	640	- 2	270	16
Aug	560	-28	278	-29
Sept	561	-12	238	-17
Oct	561	-10	230	- 2
Nov	474	0	210	2
Dec	492	1	220	- 1
Jan '71	542	---	262	----
Feb	532	12	226	26
Mar	480	5	194	12

*Effluent concentration in mg/1.

APP. IV: 5. ACIDITY AND ALKALINITY REMOVALS (%)

Date	Acidity		Alkalinity	
	Eff Conc**	%Removal	Eff Conc**	% Removal
June '70	28	42	116	0
July	34	32	152	-43
Aug	32	38	120	- 3
Sept	32	36	108	7
Oct	38	17	122	5
Nov	24	45	152	-17
Dec	46	4	134	- 6
Jan '71	56	---	152	---
Feb	68	3	150	-34
Mar	60	-20	152	-19
Apr*	--	---	---	---
May*	--	---	---	---
June*	--	---	---	---

*Closed for conversion to 4' pond.

**Effluent concentration in mg/l.

APP. IV: 6. NITROGEN REMOVALS (%)

Month	Organic N		Ammonia		Nitrate		Nitrite	
	Eff*	% Rem	Eff*	% Rem	Eff*	% Rem	Eff*	Rem
Jun '70	12.67	27	3.85	59	.17	30	.0054	-980
July	14.92	33	6.85	42	.16	-14	.0033	-700
Aug	17.62	12	7.82	28	.11	9	.0070	-84
Sept	14.27	48	6.13	46	.14	27	.0122	-( )
Oct	15.84	30	7.88	57	.15	-15	.0000	0
Nov	------	--	-----	--	---	---	.0000	0
Dec	------	--	-----	--	---	---	------	---
Jan '71	16.45	9	5.38	38	.17	-13	.0000	0
Feb	17.29	34	5.81	61	.21	-24	.0017	-( )
Mar	18.29	33	6.07	42	.17	11	.0000	0

APP. IV: 7. PHOSPHATE REMOVALS (%)

Month	Total Phosphates Eff*	Total Phosphates % Rem	Orthophosphates Eff*	Orthophosphates % Rem
June '70	36.0	- 8	35.1	- 8
July	31.1	4	30.3	4
Aug	38.5	-14	28.2	-14
Sept	25.5	---	23.5	---
Oct	22.0	---	19.5	---
Nov	----	---	----	---
Dec	----	---	----	---
Jan '71	30.1	- 3	29.4	- 6
Feb	30.2	-11	30.1	-10
Mar	31.0	-12	30.0	-13

*Effluent concentration in mg/l.

APP. IV: 8. TOTAL COLONY COUNTS (ORGANISMS/ml)

Feb. 19/69 - Mar. 15/71

Total Plate Count		Number of Samples with Indicated Counts/ml				
		$<10^4$	10^4	10^5	10^6	10^7
25°C	Inf	--	--	18	72	7
	Eff 1	--	6	66	24	5
37°C	Inf	--	--	1	19	62
	Eff 1	--	--	2	38	42

APP. IV: 9. TOTAL COLONY REMOVAL (%)

Feb. 19/69 - Mar. 10/71

Total Plate Count		Number of Samples with Indicated % Removals						
		<0	0-20	21-40	41-60	61-80	81-90	>90
Pond 1	25°C	9	5	12	9	23	24	14
	37°C	14	11	23	17	18	13	3

APP. IV: 10. BACTERIA GROUPS (ORGANISMS/ml)

Feb. 19/70 - Dec. 30/70

37°C Bacterial Group	Number of Samples with Indicated Counts/ml $<10^2$	10^2	10^3	10^4	10^5	$>10^5$
Enterobacter						
Inf	21	9	23	27	9	1
Eff 1	56	7	21	5	4	0
Alcaligenes						
Inf	16	13	23	23	15	0
Eff 1	22	23	27	15	4	2
Escherichia						
Inf	0	0	5	31	40	9
Eff 1	15.	3	38	27	7	3
Klebsiella						
Inf	18	8	27	30	6	1
Eff 1	67	7	15	3	0	1
Pseudomonas						
Inf	40	14	18	17	1	0
Eff 1	46	16	21	8	1	1
Proteus						
Inf	20	6	23	31	9	1
Eff 1	51	18	7	6	1	0
Intermediate Coliforms						
Inf	2	11	41	27	8	1
Eff 1	23	13	49	7	1	0
Providence						
Inf	46	13	23	8	0	0
Eff 1	68	10	13	2	0	0

APPENDIX V

Two-Pond System

APP. V: 1. INFLUENT FLOW (gal/day), BOD (mg/l & lbs/acre/day), and DT (days)

Month	Influent Flow $X10^3$ gal/day	Influent BOD mg/l	Influent BOD lb/acre/day	Theoretical DT days
Sept '72	133.9	142	179	7.7
Oct	152.1	104	148	6.7
Nov	268.1	102	254	3.9
Dec	237.7	151	337	4.3
Jan '73	130.7	157	194	7.9
Feb	79.9	176	133	12.9
Mar	106.6	173	173	9.7
Apr	131.2	152	188	7.9
May	109.0	145	148	9.5
June	179.7	104	175	5.7
Jul 1-18	115.2	185	200	9.0
Average	149.5	145	194	7.7

APP. V: 2. BOD REMOVALS (%)

Month	Pond 2		Pond 1		Total
	Eff 2*	% Rem	Eff 1*	% Rem	% Rem
Sept '72	51	65	39	24	73
Oct	50	52	42	16	60
Nov	70	32	38	46	63
Dec	70	54	55	22	64
Jan '73	62	61	48	23	70
Feb	55	69	51	8	72
Mar	50	72	34	32	81
Apr	67	56	49	27	68
May	70	52	51	28	65
June	63	40	55	13	48
July 1-19	46	76	41	11	78
Average	59	57	46	23	67

APP. V: 3. BOD REMOVALS (%)

Month	Pond 2		Pond 1		Total
	Eff 2*	% Rem	Eff 1*	% Rem	% Rem
Sept '72	142	36	117	18	47
Oct	142	29	97	32	52
Nov	103	34	97	6	38
Dec	103	62	111	- 8	59
Jan '73	126	32	130	- 3	29
Feb	124	48	157	-27	35
Mar	150	36	153	- 2	35
Apr	139	42	143	- 3	40
May	124	36	123	1	37
June	92	41	101	-10	35
July	117	45	98	16	54
Average	124	40	121	2	42.

*Effluent concentrations in mg/1.

APP. V: 4. SOLIDS REMOVALS (%)

Month	Total Solids				Total	Suspended Solids				Total
	Pond 2		Pond 1		%Rem	Pond 2		Pond 1		%Rem
	Eff*	%Rem	Eff*	%Rem		Eff*	%Rem	Eff*	%Rem	
Sept '72	---	---	---	---	--	.554	59	.721	-30	47
Oct	---	---	---	---	--	.708	65	.832	-18	59
Nov	---	---	---	---	--	.927	47	.467	50	74
Dec	---	---	---	---	--	2.184	27	.584	73	80
Jan '73	---	---	---	---	--	1.034	46	.668	35	65
Feb	381	27	480	-26	8	.155	58	.200	-29	46
Mar	---	---	---	---	--	.732	50	1.179	-61	19
Apr	338	22	370	- 9	15	.963	44	1.051	- 9	39
May	388	42	331	15	50	.725	56	.868	-20	48
June	518	-33	322	48	17	.805	37	.524	35	59
July	372	16	375	- 1	16	.877	43	.710	19	54

*Effluent concentrations are in mg/l.

APP. V: 5. ALKALINITY REMOVALS (%)

Date	Pond 2		Pond 1		Total
	Eff 2*	% Rem	Eff 1*	% Rem	% Rem
Sept '72	163	- 5	124	24	20
Oct	146	10	139	5	15
Nov	145	5	180	-24	-18
Dec	141	9	155	-10	0
Jan '73	140	0	139	1	1
Feb	129	15	122	5	20
Mar	143	---	---	---	---
Apr	137	17	129	6	22
May	146	4	147	- 1	3
June	143	2	135	6	8

*Effluent concentrations in mg/1.

APP. V: 6. NITROGEN REMOVALS (%)

Month	Organic Nitrogen Pond 2 Eff*	Organic Nitrogen Pond 2 %Rem	Organic Nitrogen Pond 1 Eff*	Organic Nitrogen Pond 1 %Rem	Total %Rem	Ammonia Pond 2 Eff*	Ammonia Pond 2 %Rem	Ammonia Pond 1 Eff*	Ammonia Pond 1 %Rem	Total %Rem	Nitrates Pond 2 Eff*	Nitrates Pond 2 %Rem	Nitrates Pond 1 Eff*	Nitrates Pond 1 %Rem
Sept '72	19.10	41	16.32	15	50	12.5	---	7.5	---	---	.07	30	.09	-29
Oct	25.56	25	14.78	42	56	12.6	42	7.9	37	64	.09	-29	.09	0
Nov	-----	---	16.63	---	7	----	---	9.7	---	6	.13	0	.11	15
Dec	16.51	---	18.86	-14	---	----	---	13.4	---	---	.10	23	.10	0
Jan '73	18.06	51	14.49	20	61	10.1	60	7.7	24	70	.10	-43	.12	-20
Feb	19.38	53	17.81	8	57	10.1	62	6.1	39	77	.08	72	.10	-25
Mar	18.97	---	17.04	10	---	7.9	9	7.5	4	13	.23	18	.19	17
Apr	19.32	24	17.57	9	31	9.2	37	7.6	17	48	.18	31	.16	11
May	17.93	48	16.09	10	53	9.4	---	7.0	26	---	.22	-69	.10	55
June	15.05	---	13.55	10	---	7.8	54	9.5	-23	43	.10	-100	.10	0
July	17.94	10	12.89	28	35	5.4	59	5.3	2	60	.11	-22	.09	18

*Effluent concentrations are in mg/l.

APP. V: 7. ORTHOPHOSPHATE REMOVALS (%)

Month	Pond 2		Pond 1		Total
	Eff 2*	% Rem	Eff 1*	% Rem	% Rem
Sept '72	45.5	-76	38.2	16	-48
Oct	40.3	4	45.0	-12	- 8
Nov	37.7	-24	26.3	4	-20
Dec	40.7	-23	39.0	4	-18
Jan '73	24.4	-15	27.1	-11	-27
Feb	44.3	-56	17.2	61	40
Mar	42.6	- 3	41.7	2	- 1
Apr	39.1	-13	36.2	8	- 4
May	21.3	12	22.2	- 4	8
June	12.8	14	13.0	- 1	14
July	29.8	-102	31.5	- 6	-114

*Effluent concentrations in mg/l.

APP. V: 7. TOTAL COLONY COUNT (ORGANISMS/ml)

Aug. 30/72 - July 18/73

37°C Total Plate Count	Number of Samples with Indicated Counts/ml $<10^4$	10^4	10^5	10^6	10^7
Inf 2	--	--	--	19	17
Eff 2	--	--	--	26	10
Eff 1	--	1	7	23	9

APP. V: 8. COLIFORM COUNTS (ORGANISMS/ml)

Sept. 1972 - July 18/73

37°C Coliform Group	Number of Samples with Indicated Counts/ml					
	$<10^2$	10^2	10^3	10^4	10^5	$>10^5$
Total Coliforms						
Inf 2	1	1	--	7	26	3
Eff 2	5	3	11	16	3	--
Eff 1	7	5	12	12	2	--
Fecal Coliforms						
Inf 2	2	1	9	11	15	--
Eff 2	10	9	11	8	--	--
Eff 1	12	10	9	5	2	--
Escherichia Coliforms						
Inf 2	19	2	8	4	5	--
Eff 2	23	1	8	6	--	--
Eff 1	29	1	5	3	--	--

APP. V: 9. TOTAL COLONY REMOVAL (%)

Aug. 30/72 - July 18/73

37°C Total Plate Count	Number of Samples with Indicated % Removals <0	0-20	21-40	41-60	61-80	81-90	>90
Pond 2	7	5	6	4	12	7	1
Ponds 2 & 1	2	2	9	5	8	7	9

APP. V: 10. COLIFORM REMOVAL (%)

Sept. 20/72 - Jul 18/73

37°C Coliform Group	Number of Samples with Indicated % Removals						
	<0	0-39	40-59	60-79	80-89	90-99	>99
Total Coliforms							
Pond 2	3	1	2	5	4	13	9
Ponds 2 & 1	2	2	--	1	4	15	14
Fecal Coliforms							
Pond 2	4	2	--	--	3	15	11
Ponds 2 & 1	4	5	--	--	--	13	11
E. coli							
Pond 2	6	2	--	--	1	7	5
Ponds 2 & 1	7	1	--	--	--	6	7

APPENDIX VI

Three-Pond System

APP. VI: 1. INFLUENT FLOW (gal/day), BOD (mg/l & lbs/acre/day), AND DT (days)

Month	Influent Flow $X10^3$ gal/day	Influent BOD mg/l	Influent BOD lb/acre/day	Theoretical DT (days) Pond 3	Theoretical DT (days) Pond System
July 19-31 '73	106.1	120	116	0.51	10.3
Aug	119.6	100	109	0.45	9.1
Sept	141.7	117	151	0.38	7.7
Oct	200.2	132	240	0.27	5.5
Nov	116.7	124	132	0.46	9.4
Dec	102.5	113	105	0.53	10.6
Average	131.1	118	143	0.43	8.8

APP. VI: 2. BOD REMOVALS (%)

Month	Pond 3		Pond 2		Pond 1		Total %Rem For 3 Ponds
	Eff*	%Rem	Eff*	%Rem	Eff*	%Rem	
July '73	90	25	29	68	30	-3	75
Aug	108	-8	52	52	41	21	59
Sept	107	9	43	60	30	30	74
Oct	66	50	31	53	22	29	83
Nov	57	54	32	44	24	25	81
Dec	53	53	31	42	24	23	79
Average	80	31	36	53	29	21	75

*Effluent concentrations are in mg/l.

APP. VI: 3. COD REMOVALS (%)

Month	Pond 3		Pond 2		Pond 1		Total %Rem For 3 Ponds
	Eff*	%Rem	Eff*	%Rem	Eff*	%Rem	
July '73	124	41	117	6	98	16	54
Aug	133	39	103	23	110	-7	50
Sept	202	24	132	35	124	6	53
Oct	160	55	112	30	111	1	68
Nov	98	64	118	-20	87	26	68
Dec	154	50	148	4	107	28	65
Average	145	46	122	14	106	12	60

*Effluent concentration are in mg/l.

APP. VI: 4. SOLIDS REMOVALS (%)

TOTAL SOLIDS

Month	Pond 3		Pond 2		Pond 1		Total %Rem For 3 Ponds
	Eff*	%Rem	Eff*	%Rem	Eff*	%Rem	
July '73	290	35	372	-28	375	-1	16
Aug	644	--	435	32	444	-2	--
Sept	628	-36	503	20	434	14	6
Oct	430	-8	453	-5	452	0	-13
Nov	380	6	419	-10	930	-122	-129
Dec	376	16	498	-32	560	-12	-26

SETTLEABLE SOLIDS

Month	Pond 3	
	Eff*	%Rem
July '73	.17	98
Aug	.25	97
Sept	.60	90
Oct	.59	92
Nov	.28	97
Dec	.17	98

*Effluent concentration are in mg/1.

APP. VI: 5. ALKALINITY REMOVALS (%)

Date	Pond 3		Pond 2		Pond 1		Total %Rem For 3 Ponds
	Eff*	%Rem	Eff*	%Rem	Eff*	%Rem	
Jul '73	---	---	102	11	96	6	16
Aug	143	-1	132	8	134	-2	5
Sept	154	-10	151	2	123	19	12
Oct	183	-17	139	24	130	6	17
Nov	141	-8	108	23	98	9	25
Dec	179	-24	124	31	108	13	25

*Effluent concentrations in mg/l.

APP. VI: 6. NITROGEN REMOVAL (%)

Month	Pond 3 Eff*	Pond 3 %Rem	Pond 2 Eff*	Pond 2 %Rem	Pond 1 Eff*	Pond 1 %Rem	Total % Rem For 3 Ponds
Organic Nitrogen							
July '73	----	---	17.9	---	12.9	28	35
Aug	----	---	16.9	---	13.9	18	52
Sept	----	---	----	---	----	---	--
Oct	19.4	19	14.0	28	12.3	12	48
Nov	15.3	-17	27.3	-78	8.6	68	34
Dec	18.7	46	14.2	24	7.4	48	79
Ammonia							
July '73	----	---	5.4	---	5.2	2	60
Aug	----	---	7.9	---	3.0	62	81
Sept	----	---	---	---	---	---	---
Oct	13.6	5	8.3	39	4.4	47	79
Nov	7.8	36	0.3	97	1.8	-500	85
Dec	11.5	18	4.1	64	1.9	55	87
Nitrates							
July '73	---	--	.11	---	.09	18	0
Aug	---	--	.10	---	.13	-30	-30
Sept	.06	0	.11	-83	.09	18	-50
Oct	.09	0	.15	-67	.13	13	-44
Nov	.03	57	.11	-267	.07	36	0
Dec	.03	57	.06	-100	.06	0	14

*Effluent concentrations in mg/l.

APP. VI: 7. ORTHOPHOSPHATE REMOVALS (%)

Month	Pond 3		Pond 2		Pond 1		Total %Rem For 3 Ponds
	Eff*	%Rem	Eff*	%Rem	Eff*	%Rem	
July '73	----	---	29.8	---	31.5	-6	-114
Aug	----	---	42.2	---	42.7	-1	-47
Sept	----	---	38.7	---	39.9	-3	-28
Oct	30.9	-38	27.2	12	26.8	1	-20
Nov	27.6	-14	33.8	-22	23.6	30	2
Dec	37.4	-20	35.6	5	26.0	27	17

*Effluent concentrations in mg/l.

APP. VI: 8. TOTAL COLONY COUNTS (ORGANISMS/ml)

July 19/73 - Dec. 31/73

37°C Total Plate Count	Number of Samples with Indicated Counts/ml $<10^4$	10^4	10^5	10^6	10^7
Inf 3	--	--	--	11	10
Eff 3	--	--	1	14	6
Eff 2	--	--	--	11	10
Eff 1	--	--	7	9	5

APP. VI: 9. COLIFORM COUNTS (ORGANISMS/ml)

July 19/73 - Dec. 31/73

32°C Coliform Group	Number of Samples with Indicated Counts/ml $<10^2$	10^2	10^3	10^4	10^5	$>10^5$
Total Coliform						
Inf 3	--	--	1	3	16	1
Eff 3	--	--	1	7	13	--
Eff 2	5	1	5	8	2	--
Eff 1	12	3	3	3	--	--
Fecal Coliform						
Inf 3	1	3	1	10	6	--
Eff 3	4	3	3	6	5	--
Eff 2	13	1	4	3	--	--
Eff 1	15	2	2	2	--	--
Escherichia Coliform						
Inf 3	5	2	4	9	1	--
Eff 3	9	5	3	2	2	--
Eff 2	18	--	1	2	--	--
Eff 1	17	1	2	1	--	--

APP. VI: 10. TOTAL COLONY REMOVALS (%)

July 31/73 - Dec. 31/73

37°C Total Plate Count	Number of Samples with Indicated % Removals						
	<0	0-20	21-40	41-60	61-80	81-90	>90
Pond 3	6	1	5	7	2	--	--
Ponds 3 & 2	9	8	2	2	1	--	--
Ponds 3, 2 & 1	3	1	3	3	5	3	4

APP. VI: 11. COLIFORM REMOVAL (%)

July 31/73 - Dec 31/73

Coliform Group	Number of Samples with Indicated % Removals						
	<0	0-39	40-59	60-79	80-89	90-99	>99
Total Coliform							
Pond 3	6	3	3	--	3	6	--
Ponds 3 & 2	1	1	1	3	--	7	8
Ponds 3, 2 & 1	--	--	--	--	--	6	15
Fecal Coliform							
Ponds 3	7	4	2	1	--	2	4
Ponds 3 & 2	4	--	1	--	--	4	11
Ponds 3, 2, & 1	--	--	--	--	--	7	10
Escherichia Coliform							
Pond 3	5	1	--	--	--	4	5
Ponds 3 & 2	2	--	--	--	--	5	7
Ponds 3, 2 & 1	--	--	--	--	--	7	6

APPENDIX VII

Correlation Matrix for Influent of Six-Foot Pond (Pond 1)

APP. VII: 1. CORRELATION MATRIX FOR INFLUENT OF 6-FOOT POND (POND 1)

ROW 1

1.000	-0.118	-0.081	-0.323	-0.397	-0.071	-0.009	-0.128
-0.053	-0.072	-0.140	-0.146	-0.210	-0.504	-0.063	0.650
0.308	0.342	0.362	0.495	0.242	-0.185	0.501	-0.043
0.152	-0.001	-0.251	0.006				

ROW 2

-0.118	1.000	0.867	-0.189	-0.072	-0.102	0.136	0.023
0.167	0.432	0.057	0.110	0.520	0.243	-0.095	-0.075
-0.038	-0.148	-0.098	-0.108	-0.071	0.074	-0.079	0.202
-0.008	-0.190	0.181	-0.147				

ROW 3

-0.081	0.867	1.000	-0.117	-0.022	0.076	0.160	0.074
0.182	0.304	-0.043	0.005	0.303	0.186	-0.015	0.060
-0.134	-0.119	-0.052	-0.065	0.012	0.072	0.006	0.103
-0.042	-0.137	-0.019	-0.311				

ROW 4

-0.323	-0.189	-0.117	1.000	0.795	0.036	-0.193	0.299
0.046	-0.033	-0.145	-0.157	0.073	0.209	0.082	-0.282
-0.264	-0.121	-0.104	-0.083	-0.229	0.156	-0.463	0.100
-0.008	0.185	0.481	0.131				

ROW 5

-0.397	-0.072	-0.022	0.795	1.000	0.189	-0.054	0.290
0.082	0.029	-0.053	-0.047	0.135	0.299	0.002	-0.250
-0.202	-0.191	-0.157	-0.196	-0.341	0.185	-0.427	0.112
0.016	0.301	0.348	-0.110				

APP. VII: 1. (continue)

ROW 6

-0.071	-0.103	0.076	0.036	0.189	1.000	-0.024	0.403
0.309	-0.056	-0.212	-0.211	-0.045	0.034	-0.044	0.144
-0.237	-0.183	-0.154	-0.094	-0.005	0.684	-0.035	0.236
0.067	0.095	-0.312	-0.449				

ROW 7

-0.009	0.136	0.160	-0.193	-0.054	-0.024	1.000	0.036
0.181	0.379	0.152	0.184	0.194	0.172	0.005	-0.132
0.354	0.016	0.042	0.234	-0.024	-0.116	-0.072	-0.222
0.045	0.277	-0.094	0.088				

ROW 8

-0.128	0.023	0.074	0.299	0.290	0.403	0.036	1.000
0.183	0.017	-0.504	-0.421	0.370	0.230	-0.100	-0.041
-0.154	-0.118	-0.069	-0.052	-0.061	0.323	-0.117	0.235
0.151	0.016	0.199	-0.094				

ROW 9

-0.053	0.167	0.182	0.046	0.082	0.309	0.181	0.183
1.000	0.605	0.015	-0.012	-0.096	0.164	0.000	0.009
-0.154	-0.293	-0.283	-0.029	-0.002	0.162	-0.250	-0.070
-0.040	0.076	-0.094	-0.163				

ROW 10

-0.072	0.432	0.304	-0.033	0.029	-0.056	0.379	0.017
0.605	1.000	0.004	-0.040	0.253	0.242	-0.044	-0.106
0.060	-0.046	-0.031	0.058	-0.034	-0.063	-0.185	-0.026
0.027	-0.001	0.043	0.125				

APP. VII: 1. (continue)

ROW 11

-0.140	0.057	-0.043	-0.145	-0.053	-0.212	0.152	-0.504
0.015	0.004	1.000	0.984	-0.165	-0.031	-0.032	0.009
0.231	-0.295	-0.373	-0.311	-0.039	-0.039	-0.224	0.082
0.024	0.046	0.006	0.096				

ROW 12

-0.146	0.110	0.005	-0.157	-0.047	-0.211	0.184	-0.421
-0.012	-0.040	0.984	1.000	-0.116	-0.027	-0.038	0.029
0.227	-0.331	-0.399	-0.327	-0.044	-0.000	-0.221	0.079
0.037	0.045	0.007	0.032				

ROW 13

-0.210	0.520	0.303	0.073	0.135	-0.045	0.194	0.370
-0.096	0.253	-0.165	-0.116	1.000	0.421	-0.195	-0.390
0.007	0.134	0.187	0.163	-0.274	-0.042	-0.259	0.209
0.344	0.064	0.307	0.143				

ROW 14

-0.504	0.243	0.186	0.209	0.299	0.034	0.172	0.230
0.164	0.242	-0.031	-0.027	0.421	1.000	0.053	-0.684
-0.048	-0.223	-0.215	-0.172	-0.481	-0.018	-0.542	0.283
-0.081	0.186	0.350	0.251				

ROW 15

-0.063	-0.095	-0.015	0.082	0.002	-0.044	0.005	-0.100
0.000	-0.044	-0.032	-0.038	-0.195	0.053	1.000	-0.160
-0.116	-0.212	-0.216	-0.122	-0.038	0.034	-0.084	-0.207
-0.285	0.028	0.075	0.174				

APP. VII: 1. (continue)

ROW 16

0.650	-0.075	0.060	-0.282	-0.250	0.144	-0.132	-0.041
0.009	-0.106	0.009	0.029	-0.390	-0.684	-0.160	1.000
0.130	0.180	0.152	0.052	0.641	0.180	0.366	-0.033
0.103	-0.352	-0.382	-0.357				

ROW 17

0.308	-0.038	-0.134	-0.264	-0.202	-0.237	0.354	-0.154
-0.154	0.060	0.231	0.227	0.007	-0.048	-0.116	0.130
1.000	0.045	0.012	0.121	-0.106	-0.292	0.195	0.102
0.222	0.111	0.298	0.263				

ROW 18

0.342	-0.148	-0.119	-0.121	-0.191	-0.183	0.016	-0.118
-0.293	-0.046	-0.295	-0.331	0.134	-0.223	-0.212	0.180
0.045	1.000	0.979	0.571	0.268	-0.435	0.222	0.147
0.389	-0.241	-0.154	0.016				

ROW 19

0.362	-0.098	-0.052	-0.104	-0.157	-0.154	0.042	-0.069
-0.283	-0.031	-0.373	-0.399	0.187	-0.215	-0.216	0.152
0.012	0.979	1.000	0.652	0.188	-0.444	0.268	0.112
0.389	-0.147	-0.198	-0.063				

ROW 20

0.495	-0.108	-0.065	-0.083	-0.196	0.094	0.234	-0.052
-0.029	0.058	-0.311	-0.327	0.163	-0.172	-0.122	0.052
0.121	0.571	0.652	1.000	0.033	-0.473	0.173	-0.168
0.259	0.225	-0.236	0.098				

APP. VII: 1. (continue)

ROW 21

0.242	-0.071	0.012	-0.229	-0.341	-0.005	-0.024	-0.161
-0.002	-0.034	-0.039	-0.044	-0.274	-0.481	-0.038	0.641
-0.106	0.268	0.188	0.033	1.000	0.122	0.053	-0.198
0.075	-0.696	-0.325	-0.098				

ROW 22

0.185	0.074	0.072	0.156	0.185	0.684	-0.116	0.323
0.162	-0.063	-0.039	-0.000	-0.042	-0.018	0.034	0.180
-0.292	-0.435	-0.444	-0.473	0.122	1.000	-0.171	0.260
-0.132	-0.154	0.019	-0.310				

ROW 23

0.501	-0.079	0.006	-0.463	-0.427	-0.035	-0.072	-0.117
-0.250	-0.185	-0.224	-0.221	-0.259	-0.542	-0.084	0.366
0.195	0.222	0.268	0.173	0.053	-0.171	1.000	-0.207
0.124	0.040	-0.320	-0.248				

ROW 24

-0.043	0.202	0.103	0.100	0.112	0.236	-0.222	0.235
-0.070	-0.026	0.082	0.079	0.209	0.283	-0.207	-0.033
-0.102	0.147	0.112	-0.168	-0.198	0.260	-0.207	1.000
0.170	-0.368	0.439	-0.041				

ROW 25

0.152	-0.008	-0.042	-0.008	0.016	0.067	0.045	0.151
-0.040	0.027	0.024	0.037	0.344	-0.081	-0.285	0.103
0.222	0.398	0.398	0.259	0.075	-0.132	0.124	0.170
1.000	-0.030	-0.127	-0.291				

APP. VII: 1. (continue)

ROW 26

-0.001	-0.190	-0.137	0.185	0.301	0.095	0.277	0.016
0.076	-0.001	0.046	0.045	0.064	0.186	0.028	-0.352
0.111	-0.241	-0.147	0.225	-0.696	-0.154	0.040	-0.368
-0.030	1.000	-0.129	0.001				

ROW 27

-0.251	0.181	-0.019	0.481	0.348	-0.312	-0.094	0.199
-0.094	0.043	0.006	0.007	0.307	0.350	0.075	-0.382
0.298	-0.154	-0.198	-0.236	-0.325	0.019	-0.320	-0.439
-0.127	-0.129	-1.000	0.521				

ROW 28

0.006	-0.147	-0.311	0.131	-0.110	-0.449	0.088	-0.094
-0.163	0.125	0.096	0.032	0.143	0.251	0.174	-0.357
0.263	0.016	-0.063	0.098	-0.,-09	-0.310	0.248	-0.041
-0.291	0.001	0.521	1.000				

APPENDIX VIII

Correlation Matrix for Effluent of Six-Foot Pond (Pond 1)

APP. VIII: 1. CORRELATION MATRIX FOR EFFLUENT OF 6-FOOT POND (POND 1)

ROW 1

1.000	-0.145	-0.249	-0.012	0.228	0.057	-0.337	-0.013
-0.108	-0.082	-0.362	-0.208	-0.190	0.012	0.259	0.216
-0.063	0.132	0.115	-0.134	-0.163	-0.162	0.501	-0.121
0.058	0.006	-0.050	0.025				

ROW 2

-0.145	1.000	0.608	0.172	-0.087	-0.239	0.030	0.105
0.147	0.185	0.218	0.260	0.175	0.199	0.043	-0.168
-0.074	-0.156	-0.104	0.073	0.123	0.042	0.034	0.056
-0.347	-0.049	0.295	0.203				

ROW 3

-0.249	0.608	1.000	0.057	-0.352	-0.165	0.214	0.062
0.257	0.346	0.291	0.352	0.336	0.056	0.211	-0.361
-0.079	0.007	0.069	0.317	0.042	-0.004	0.021	0.195
-0.002	-0.100	0.223	0.048				

ROW 4

-0.012	0.172	0.057	1.000	0.169	-0.188	0.042	0.143
-0.075	0.081	0.267	0.265	0.124	0.308	-0.098	0.101
0.059	0.074	0.109	0.053	0.096	-0.089	0.035	0.033
-0.139	-0.076	0.338	0.325				

ROW 5

0.228	-0.087	-0.352	0.169	1.000	0.392	-0.034	0.212
-0.266	-0.116	-0.226	-0.221	-0.088	0.344	-0.008	0.284
0.107	-0.130	-0.080	-0.059	0.082	-0.017	-0.049	-0.341
-0.210	0.104	-0.172	0.179				

APP. VIII: 1. (continue)

ROW 6

0.057	-0.239	-0.165	-0.188	0.392	1.000	0.232	0.404
-0.098	-0.069	-0.262	-0.287	-0.270	-0.164	0.177	0.260
0.148	0.034	0.039	-0.155	0.160	0.097	-0.039	-0.135
-0.174	0.071	-0.346	-0.206				

ROW 7

-0.337	0.030	0.214	0.042	-0.034	0.232	1.000	0.027
0.048	0.067	0.195	0.123	-0.311	-0.261	0.199	0.167
0.184	0.176	0.135	-0.035	0.763	-0.198	-0.164	0.118
-0.312	-0.059	-0.042	0.102				

ROW 8

-0.013	0.105	0.062	0.143	0.212	0.404	0.027	1.000
0.019	0.058	0.088	0.064	0.215	0.160	0.093	-0.031
-0.101	-0.084	-0.061	-0.200	-0.159	0.078	-0.030	0.209
0.063	-0.327	0.090	-0.094				

ROW 9

-0.108	0.147	0.257	-0.075	-0.266	-0.098	0.048	0.019
1.000	0.789	0.205	0.175	0.495	0.209	0.243	-0.060
0.414	0.013	0.016	0.075	0.001	-0.041	-0.040	0.155
0.000	0.105	0.441	0.016				

ROW 10

-0.082	0.185	0.346	-0.081	-0.116	-0.069	0.067	0.058
0.789	1.000	0.043	0.041	0.590	0.199	0.245	-0.311
0.203	-0.098	-0.096	0.151	0.011	0.001	-0.077	0.272
-0.000	-0.087	0.433	0.144				

ROW 11

-0.362	0.218	0.291	0.267	-0.226	-0.262	0.195	0.088
0.205	0.043	1.000	0.872	0.463	0.543	0.050	-0.004
0.254	0.143	0.154	0.220	0.064	-0.237	-0.312	0.256
0.001	-0.239	0.461	0.508				

ROW 12

-0.208	0.260	0.352	0.265	-0.221	-0.287	0.123	0.064
0.175	0.041	0.872	1.000	0.382	0.517	0.193	-0.059
0.240	0.098	0.116	0.184	0.050	-0.233	-0.001	0.248
0.008	-0.294	0.471	0.483				

ROW 13

-0.190	0.175	0.336	0.124	-0.088	-0.270	-0.311	0.215
0.496	0.590	0.463	0.382	1.000	0.643	0.128	-0.421
0.072	-0.120	-0.055	0.210	-0.491	0.017	-0.215	0.321
0.280	-0.261	0.564	0.267				

ROW 14

0.012	0.199	0.056	0.308	0.344	-0.164	-0.261	0.160
0.209	0.199	0.543	0.517	0.643	1.000	0.006	0.130
0.274	-0.038	0.021	0.279	-0.245	-0.259	-0.066	-0.075
0.052	-0.169	0.347	0.407				

ROW 15

0.259	0.043	0.211	-0.098	-0.008	0.177	0.199	0.093
0.243	0.245	0.050	0.193	0.128	0.006	1.000	-0.029
0.092	0.239	0.298	-0.016	0.048	0.006	0.300	0.324
-0.062	-0.290	0.223	0.038				

APP. VIII: 1. (continue)

ROW 16

-0.216	-0.168	-0.361	0.101	0.284	0.260	0.167	-0.031
-0.060	-0.311	-0.004	-0.059	-0.421	0.130	-0.029	1.000
0.402	0.225	0.182	0.015	0.319	-0.271	0.107	-0.353
-0.205	0.145	-0.396	-0.223				

ROW 17

-0.063	-0.074	-0.079	0.059	0.107	0.148	0.184	-0.101
0.414	0.203	0.254	0.240	0.072	0.274	0.092	0.402
1.000	0.080	0.084	0.083	0.090	-0.113	-0.124	-0.164
0.120	0.258	-0.042	-0.016				

ROW 18

0.132	-0.156	0.007	0.074	-0.130	0.034	0.176	-0.084
0.013	-0.096	0.143	0.098	-0.120	-0.038	0.239	0.225
0.080	1.000	0.978	0.504	0.290	-0.364	0.172	-0.080
-0.104	0.194	-0.007	0.174				

ROW 19

0.115	-0.104	0.069	0.109	-0.080	0.039	0.135	-0.061
0.016	-0.096	0.154	0.116	-0.055	0.021	0.298	0.182
0.084	0.978	1.000	0.579	0.209	-0.324	0.192	-0.096
-0.098	0.199	0.010	0.170				

ROW 20

-0.134	0.073	0.317	0.053	-0.059	-0.155	-0.035	-0.200
0.075	0.151	0.220	0.184	0.210	0.279	-0.016	0.015
0.083	0.504	0.579	1.000	0.009	-0.368	0.023	-0.322
0.060	0.302	-0.126	0.220				

APP. VIII: 1. (continue)

ROW 21

-0.163	0.123	0.042	0.096	0.082	0.160	0.763	-0.159
0.001	0.011	0.064	0.050	-0.491	-0.245	0.048	0.319
0.090	0.290	0.209	0.009	1.000	-0.243	-0.061	-0.094
-0.610	0.110	-0.133	0.206				

ROW 22

-0.162	0.042	-0.004	-0.089	-0.017	0.097	-0.198	0.078
-0.041	0.001	-0.237	-0.233	0.017	-0.259	0.006	-0.271
-0.113	-0.364	-0.324	-0.368	-0.243	1.000	-0.114	0.323
0.126	-0.086	0.064	-0.323				

ROW 23

0.501	0.034	0.021	0.035	-0.049	-0.039	-0.164	-0.030
-0.040	-0.077	-0.312	-0.001	-0.215	-0.066	0.300	0.107
-0.124	0.172	0.192	0.023	-0.061	-0.114	1.000	-0.180
0.056	0.050	-0.126	-0.164				

ROW 24

-0.121	0.056	0.195	0.033	-0.341	-0.135	0.118	0.209
0.155	0.272	0.256	0.248	0.321	-0.075	0.324	-0.353
-0.164	-0.080	-0.080	-0.096	-0.322	-0.094	0.323	-0.180
1.000	-0.032	-0.811	0.612	-0.065			

ROW 25

0.058	-0.347	-0.002	-0.139	-0.210	-0.174	-0.312	0.063
0.000	-0.000	0.001	0.008	0.280	0.052	-0.062	-0.205
0.120	-0.104	-0.098	0.060	-0.610	0.126	0.056	-0.032
1.000	0.108	-0.189	-0.231				

APP. VIII: 1. (continue)

ROW 26

0.006	-0.049	-0.100	-0.076	0.104	0.071	-0.059	-0.327
0.105	-0.087	-0.239	-0.294	-0.261	-0.169	-0.290	0.145
0.258	0.194	0.199	0.302	0.110	-0.086	0.050	-0.811
0.108	1.000	-0.466	0.051				

ROW 27

-0.050	0.295	0.223	0.338	-0.172	-0.346	-0.042	0.090
0.441	0.433	0.461	0.471	0.564	0.347	0.223	-0.396
-0.042	-0.007	0.010	-0.126	-0.133	0.064	-0.126	0.612
-0.189	-0.466	1.000	0.487				

ROW 28

0.025	0.203	0.048	0.325	0.179	-0.206	0.102	-0.094
0.016	0.144	0.508	0.483	0.267	0.407	0.038	-0.223
-0.016	0.174	0.170	0.220	0.206	-0.323	-0.164	-0.065
-0.231	0.051	0.487	1.000				

APPENDIX IX

Correlation Matrix for Influent and Effluent of Six-Foot Pond (Pond 1)

APP. IX: 1. CORRELATION MATRIX FOR INFLUENT AND EFFLUENT OF 6-FOOT POND (POND 1)

ROW 1

1.000	0.212	0.203	-0.361	-0.268	-0.130	-0.045	-0.242
-0.003	-0.007	0.023	0.049	-0.197	0.433	-0.097	0.530
0.167	0.132	0.140	0.257	0.164	-0.137	0.376	-0.235
0.156	0.135	-0.351	-0.076				

ROW 2

0.212	1.000	0.721	-0.248	-0.030	-0.055	0.163	-0.099
0.174	0.373	0.069	0.111	0.307	0.198	0.220	0.064
0.038	-0.218	-0.189	-0.183	-0.059	0.054	-0.016	0.075
-0.191	-0.146	0.074	-0.022				

ROW 3

0.203	0.721	1.000	-0.298	-0.079	0.275	0.198	0.077
0.178	0.148	0.005	0.058	0.090	-0.014	-0.005	0.365
-0.009	-0.102	-0.052	-0.023	0.134	0.129	0.203	0.048
-0.023	-0.120	-0.267	-0.327				

ROW 4

-0.361	-0.248	-0.298	1.000	0.657	0.002	-0.219	0.253
0.097	0.019	-0.223	-0.225	0.107	0.235	0.126	-0.303
0.318	-0.282	-0.283	-0.159	-0.244	0.055	-0.475	0.022
-0.059	0.195	0.462	0.251				

ROW 5

-0.268	-0.030	-0.079	0.657	1.000	0.162	-0.026	0.175
0.111	0.061	0.031	0.044	0.239	0.394	0.001	-0.366
0.280	-0.336	-0.304	-0.167	-0.392	0.046	-0.510	-0.018
0.012	0.436	0.188	-0.088				

APP. IX: 1. (continue)

ROW 6

-0.130	-0.055	0.275	0.002	0.162	1.000	0.103	0.453
0.266	-0.113	-0.117	-0.128	0.013	0.118	-0.039	0.100
-0.147	-0.112	-0.088	-0.018	-0.005	0.660	-0.064	0.253
0.083	0.109	-0.276	-0.397				

ROW 7

-0.045	0.163	0.198	-0.219	-0.026	C.103	1.000	0.201
0.138	0.354	0.089	0.105	0.189	0.274	0.013	-0.167
0.126	0.173	0.204	0.384	-0.005	-0.152	-0.062	-0.085
0.043	0.145	-0.132	0.110				

ROW 8

-0.242	-0.099	0.077	0.253	0.175	0.453	0.201	1.000
0.196	-0.017	-0.307	-0.261	0.340	0.347	-0.071	-0.094
-0.097	-0.022	0.008	0.000	-0.142	0.299	-0.142	0.283
0.134	0.026	0.190	0.005				

ROW 9

-0.003	0.174	0.178	0.097	0.111	0.266	0.138	0.196
1.000	0.601	0.050	0.030	-0.023	0.174	-0.019	-0.022
-0.123	-0.277	-0.277	-0.025	-0.023	0.116	-0.272	-0.117
0.001	0.132	-0.094	0.049				

ROW 10

-0.007	0.373	0.148	0.019	0.061	-0.113	0.354	-0.017
0.601	1.000	0.029	-0.002	0.298	0.275	-0.066	-0.147
0.138	-0.055	-0.061	0.021	-0.034	-0.094	-0.215	0.048
0.067	0.019	-0.098	0.053				

ROW 11

0.023	0.069	0.005	-0.223	0.031	-0.117	0.089	-0.307
0.050	0.029	1.000	0.982	0.019	0.046	-0.060	-0.024
0.017	-0.207	-0.268	-0.155	-0.034	-0.094	-0.213	0.069
0.052	0.014	-0.066	0.085				

APP. IX: 1. (continue)

ROW 12

0.049	0.111	0.058	-0.225	0.044	-0.128	0.105	-0.261
0.030	-0.002	0.982	1.000	0.053	0.043	-0.068	-0.004
0.006	-0.265	-0.318	-0.201	-0.044	-0.053	-0.215	0.048
0.067	0.019	-0.098	0.053				

ROW 13

-0.197	0.307	0.090	0.107	0.239	0 013	0.189	0.340
-0.023	0.298	0.019	0.053	1.000	0.596	-0.211	-0.431
-0.027	0.072	0.114	0.059	-0.305	-0.008	-0.355	0.335
0.367	0.003	0.238	-0.081				

ROW 14

-0.433	0.198	-0.014	0.235	0.394	0.118	0.274	0.347
0.174	0.275	0.046	0.043	0.596	1.000	0.031	-0.691
-0.071	-0.195	-0.149	0.029	-0.457	-0.049	-0.566	0.292
-0.042	0.182	0.279	0.184				

ROW 15

-0.097	0.220	-0.005	0.126	0.001	-0.039	0.013	-0.071
-0.019	-0.066	-0.060	-0.068	-0.211	0.031	1.000	-0.149
-0.120	-0.185	-0.187	-0.116	-0.034	0.050	-0.071	-0.181
-0.291	0.021	0.124	0.272				

ROW 16

0.530	0.064	0.365	-0.303	-0.366	0.100	-0.167	-0.094
-0.022	-0.147	-0.024	-0.004	-0.431	-0.691	-0.149	1.000
0.152	0.196	0.148	0.003	0.638	0.164	0.369	-0.051
0.102	-0.353	-0.392	-0.275				

ROW 17

0.167	0.038	-0.009	0.318	0.280	-0.147	0.126	-0.097
-0.123	0.138	0.017	0.006	-0.027	-0.071	-0.120	0.152
1.000	-0.079	-0.097	0.039	-0.123	-0.271	0.123	0.119
0.239	0.088	0.248	0.055				

APP. IX: 1. (continue)

ROW 18

0.132	-0.218	-0.102	-0.282	-0.336	-0.112	0.173	-0.022
-0.277	-0.055	-0.207	-0.265	0.072	-0.195	-0.185	0.196
-0.079	1.000	0.984	0.637	0.299	-0.381	0.250	0.183
0.344	-0.216	-0.074	-0.132				

ROW 19

0.140	-0.189	-0.052	-0.283	-0.304	-0.088	0.204	0.008
-0.277	-0.061	-0.268	-0.318	0.114	-0.149	-0.187	0.148
-0.097	0.984	1.000	0.704	0.214	-0.397	0.282	0.173
0.349	-0.131	-0.101	-0.171				

ROW 20

0.257	-0.183	-0.023	-0.159	-0.167	-0.018	0.384	0.009
-0.025	0.021	-0.155	-0.201	0.059	0.029	-0.116	0.003
0.039	0.637	0.704	1.000	0.040	-0.424	0.123	0.038
0.246	0.170	-0.118	0.009				

ROW 21

0.164	-0.059	0.134	-0.244	-0.392	-0.005	0.005	-0.142
-0.023	-0.066	-0.034	-0.044	-0.305	-0.457	-0.034	0.638
-0.123	0.299	0.214	0.040	1.000	0.139	0.049	-0.160
0,075	-0.700	-0.279	-0.074				

ROW 22

-0.137	0.054	0.129	0.055	0.046	0.660	-0.152	0.299
0.116	-0.131	-0.094	-0.053	-0.008	-0.043	0.050	0.164
-0.271	-0.381	-0.397	-0.424	0.139	1.000	-0.137	0.212
-0.148	-0.148	0.024	-0.137				

ROW 23

0.376	-0.016	0.203	-0.475	-0.510	-0.064	-0.062	-0.142
-0.272	-0.236	-0.213	-0.215	-0.355	-0.566	-0.071	0.369
0.123	0.250	0.282	0.123	0.049	-0.137	1.000	-0.202
0.115	0.076	-0.263	-0.187				

APP. IX: 1. (continue)

ROW 24

-0.235	0.075	0.048	0.022	-0.018	0.258	-0.085	0.283
-0.117	-0.060	0.069	0.048	0.335	0.292	-0.181	-0.051
0.119	0.183	0.173	0.038	-0.160	0.212	-0.202	1.000
0.162	-0.386	0.481	-0.182				

ROW 25

0.156	-0.191	-0.023	-0.059	0.012	0.083	0.043	0.134
0.001	0.078	0.052	0.067	0.367	-0.042	0.291	0.102
0.239	0.344	0.349	0.246	0.075	-0.148	0.115	0.162
1.000	-0.045	-0.197	-0.499				

ROW 26

0.135	-0.146	-0.120	0.195	0.436	0.109	0.145	0.026
0.123	0.032	0.014	0.019	0.003	0.182	0.021	-0.353
0.088	-0.216	-0.131	0.170	-0.700	-0.148	0.076	-0.386
-0.045	1.000	-0.167	0.109				

ROW 27

-0.351	0.074	-0.267	0.462	0.188	-0.276	-0.132	0.190
-0.094	0.037	-0.066	-0.098	0.238	0.279	0.124	-0.392
0.248	-0.074	-0.101	-0.118	-0.279	0.024	-0.263	0.481
-0.197	-0.167	1.000	0.554				

ROW 28

-0.076	0.022	0.327	0.251	-0.088	-0.397	0.110	0.005
0.049	0.151	0.085	-0.053	0.081	0.184	0.272	-0.275
0.055	-0.132	-0.171	0.009	-0.074	-0.137	-0.187	-0.182
-0.449	0.109	0.554	1.000				

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APPENDIX X

Correlation Matrix for Four-Foot Pond for Data Sub-Groups

APP. X: 1. CORRELATION MATRIX FOR 4-FOOT POND FOR DATA SUB-GROUPS

ROW 1

1.00000	0.37924	0.21830	-0.63183	-0.02542	-0.24888	-0.73693
0.11956	-0.00773	0.12310	0.55940	-0.29974		

ROW 2

0.37924	1.00000	-0.18326	-0.34537	-0.08622	-0.19207	-0.19038
0.54471	0.05114	0.34614	0.55668	0.08084		

ROW 3

0.21830	-0.18326	1.00000	-0.37653	0.00540	0.29227	-0.07479
-0.64182	-0.13812	-0.59570	0.37007	0.22755		

ROW 4

-0.63183	-0.34537	-0.37653	1.00000	0.27628	0.22510	0.02060
-0.34737	-0.58204	-0.38567	-0.34438	-0.09031		

ROW 5

-0.02542	-0.08622	0.00540	0.27628	1.00000	-0.66995	-0.36039
-0.12622	-0.64063	-0.29693	-0.41995	-0.04237		

ROW 6

-0.24888	-0.19207	0.29227	0.22510	-0.66995	1.00000	0.33031
-0.56514	0.00835	-0.44084	0.43504	-0.17076		

ROW 7

-0.73693	-0.19038	-0.07479	0.02060	-0.36039	0.33031	1.00000
0.11181	0.54601	0.17753	-0.29790	0.18849		

ROW 8

0.11956	0.54471	-0.64182	-0.34737	-0.12622	-0.56514	0.11181
1.00000	0.60178	0.95054	-0.09916	0.23390		

APP. X: 1. (continue)

ROW 9

-0.00773	0.05114	-0.13812	-0.58204	-0.64063	0.00835	0.54601
0.60178	1.00000	0.76858	0.01015	0.26622		

ROW 10

0.12310	0.34614	-0.59570	-0.38567	-0.29693	-0.44084	0.17753
0.95054	0.76858	1.00000	-0.08945	0.22130		

ROW 11

0.55940	0.55668	0.37007	-0.34438	-0.41995	0.43504	-0.29790
-0.09916	0.01015	-0.08945	1.00000	-0.09356		

ROW 12

-0.29974	0.08084	0.22755	-0.09031	-0.04237	-0.17076	0.18849
0.23390	0.26622	0.22130	-0.09356	1.00000		

APPENDIX XI

Correlation Matrix for Five-Foot Pond for Data Sub-Groups

APP. XI: 1. CORRELATION MATRIX FOR 5-FOOT POND FOR DATA SUB-GROUPS

ROW 1

1.00000	-0.32665	-0.05268	0.24283	-0.75685	-0.14741	-0.20150
-0.69202	-0.85774	-0.61248	-0.38002	-037752		

ROW 2

-0.32665	1.00000	-0.68709	0.31640	-0.21088	0.09228	0.05063
0.60111	0.32819	0.37533	0.14279	-0.24711		

ROW 3

-0.05268	-0.68709	1.00000	-0.52962	0.44494	0.07149	0.27510
-0.58777	-0.00340	-0.55254	-0.10301	0.17276		

ROW 4

0.24283	0.31640	-0.52962	1.00000	-0.38413	0.00049	0.36749
0.31499	0.14159	0.32661	-0.15291	-0.30365		

ROW 5

-0.75685	-0.21088	0.44494	-0.38413	1.00000	0.13972	0.07387
0.24210	0.51247	0.39778	-0.08531	0.15406		

ROW 6

-0.14741	0.09228	0.07149	0.00049	0.13972	1.00000	0.31965
-0.03947	0.15165	-0.13922	-0.34791	0.20987		

ROW 7

-0.20150	0.05063	0.27510	0.36749	0.07387	0.31965	1.00000
0.21103	0.43781	0.02848	0.21856	0.31184		

ROW 8

-0.69202	0.60111	-0.58777	0.31499	0.24210	-0.03947	0.21103
1.00000	0.70444	0.91278	0.52296	0.31378		

APP. XI: 1. (continue)

ROW 9

-0.85774	0.32819	-0.00340	0.14159	0.51247	0.15165	0.43781
0.70444	1.00000	0.56428	0.45286	0.41677		

ROW 10

-0.61248	0.37533	-0.55254	0.32661	0.39778	-0.13922	0.02848
0.91278	0.56428	1.00000	0.29687	0.16401		

ROW 11

-0.38002	0.14279	-0.10301	-0.15291	-0.08531	-0.34791	0.21856
0.52296	0.45286	0.29687	1.00000	0.73341		

ROW 12

-0.37752	-0.24711	0.17276	-0.30365	0.15406	0.20987	0.31184
0.31378	0.41677	0.16401	0.73341	1.0000		

APPENDIX XII

Correlation Matrix for Six-Foot Pond fcr Data Sub-Groups

APP. XII: 1. CORRELATION MATRIX FOR 6-FOOT POND FOR DATA SUB-GROUPS

ROW 1

1.00000	-0.59463	0.16869	-0.86782	0.13510	-0.00179	-0.64059
-0.02507	0.07807	0.01773	0.41286	0.01453		

ROW 2

-0.59463	1.00000	-0.09187	0.62322	0.12191	0.39255	-0.03228
0.40133	0.50332	0.38902	-0.00292	-0.33547		

ROW 3

0.16869	-0.09187	1.00000	-0.10171	0.74533	0.44958	-0.29639
0.54116	0.24899	0.41544	0.07956	-0.02301		

ROW 4

-0.86782	0.62322	-0.10171	1.00000	-0.25450	-0.04882	0.62984
0.31885	0.28920	0.29445	-0.39121	-0.46693		

ROW 5

0.13510	0.12191	0.74533	-0.25450	1.00000	0.50046	-0.36023
0.56570	0.17347	0.49503	0.07724	0.27045		

ROW 6

-0.00179	0.39255	0.44958	-0.04882	0.50046	1.00000	-0.32394
0.26851	0.00954	0.13913	0.76340	-0.17023		

ROW 7

-0.64059	-0.03228	-0.29639	0.62984	-0.36023	-0.32394	1.00000
-0.03103	-0.36781	-0.04978	-0.33742	-0.04398		

ROW 8

-0.02507	0.40133	0.54116	0.31885	0.56570	0.26851	-0.03103
1.00000	0.73689	0.97979	-0.06671	-0.52030		

APP. XII: 1. (continue)

ROW 9

0.07807	0.50332	0.24899	0.28920	0.17347	0.00954	-0.36781
0.73689	1.00000	0.79126	-0.19928	-0.65123		

ROW 10

0.01773	0.38902	0.41544	0.29445	0.[illegible]9503	0.13913	-0.04978
0.97979	0.79126	1.00000	-0.14797	-0.54312		

ROW 11

0.41286	-0.00292	0.07956	-0.39121	0.07724	0.76340	-0.33742
-0.06671	-0.19928	-0.14797	1.00000	-0.18933		

ROW 12

0.01453	-0.33547	-0.02301	-0.46693	0.27045	-0.17023	-0.04398
-0.52030	-0.65123	-0.54312	-0.18933	1.00000		

APPENDIX XIII

Correlation Matrix for Two-Pond System for Data Sub-Groups

APP. XIII: 1. CORRELATION MATRIX FOR 2-POND SYSTEM FOR DATA SUB-GROUPS

ROW 1

1.00000	0.15116	-0.10300	-0.04185	-0.31281	-0.05326	-0.31244
-0.19787	-0.14004	-0.24437	0.69758	-0.50807		

ROW 2

0.15116	1.00000	0.69573	0.05021	-0.57442	-0.37822	0.51935
0.62401	0.51391	0.24956	-0.25316	0.35253		

ROW 3

-0.10300	0.69573	1.00000	-0.17118	-0.48771	-0.12972	0.64580
0.61202	0.36948	0.29916	-0.43045	0.41924		

ROW 4

-0.04185	0.05021	-0.17118	1.00000	0.66600	-0.17479	-0.21010
0.04691	-0.29454	0.28295	0.08118	-0.60378		

ROW 5

-0.31281	-0.57442	-0.48771	0.66600	1.00000	0.04874	-0.12032
-0.03069	-0.20851	0.39753	-0.03111	-0.58914		

ROW 6

-0.05326	-0.37822	-0.12972	-0.17479	0.04874	1.00000	-0.28555
-0.45906	-0.47614	-0.25168	0.08296	-0.25453		

ROW 7

-0.31244	0.51935	0.64580	-0.21010	-0.12032	-0.28555	1.00000
0.94355	0.87740	0.75245	-0.66711	0.44584		

ROW 8

-0.19787	0.62401	0.61202	0.04691	-0.03069	-0.45906	0.94355
1.00000	0.83096	0.85088	-0.63955	0.30488		

APP. XII: 1. (continue)

ROW 9

-0.14004	0.51391	0.36948	-0.29454	-0.20851	-0.47614	0.87740
0.83086	1.00000	0.55575	-0.40782	0.46276		

ROW 10

-0.24437	0.24956	0.29916	0.28295	0.39753	-0.25168	0.75245
0.85088	0.55575	1.00000	-0.66827	-0.02616		

ROW 11

0.69758	-0.25316	-0.43045	0.08118	-0.03111	0.08296	-0.66711
-0.63955	-0.40782	-0.66827	1.00000	-0.59628		

ROW 12

-0.50807	0.35253	0.41924	-0.60378	-0.58914	-0.25453	0.44584
0.30488	0.46276	-0.02616	-0.59628	1.00000		

APPENDIX XIV

Correlation Matrix for Three-Pond System for Data Sub-Groups

APP. XIV: 1. CORRELATION MATRIX FOR THREE-POND SYSTEM FOR DATA SUB-GROUPS

ROW 1

1.00000	0.84405	0.09892	0.22041	0.36692	0.88821	0.49836
0.51443	0.13203	0.04003	0.14898	0.56296		

ROW 2

0.84405	1.00000	0.48137	0.30427	0.64724	0.52261	0.45140
0.54054	0.18704	0.12774	0.29691	0.23199		

ROW 3

0.09892	0.48137	1.00000	0.40427	0.70625	-0.11365	-0.11601
0.11687	0.22961	0.18504	0.76747	-0.67631		

ROW 4

0.22041	0.30427	0.40427	1.00000	0.07262	0.18528	-0.63387
-0.56693	-0.66174	-0.77887	0.81537	-0.45711		

ROW 5

0.36692	0.64724	0.70625	0.07262	1.00000	0.12729	0.14361
0.32384	0.20516	0.53415	0.40445	-0.09576		

ROW 6

0.88821	0.52261	-0.11365	0.18528	0.12729	1.00000	0.32903
0.31558	0.04155	-0.04454	0.14905	0.58736		

ROW 7

0.49886	0.45140	-0.11601	-0.63387	0.14361	0.32903	1.00000
0.97062	0.80033	0.63299	-0.55813	0.62831		

ROW 8

0.51443	0.54054	0.11687	-0.56693	0.32384	0.31558	0.97062
1.00000	0.87109	0.71291	-0.37692	0.47475		

APP. XIV: 1. (continue)

ROW 9

0.13203	0.18704	0.22961	-0.66174	0.20516	0.04155	0.80033
0.87109	1.00000	0.78649	-0.29038	0.12977		

ROW 10

0.04003	0.12774	0.18504	-0.77887	0.03415	-0.04454	0.63299
0.71291	0.78649	1.00000	-0.34546	0.23298		

ROW 11

0.14898	0.29691	0.76747	0.81537	0.40445	0.14905	-0.55813
-0.37692	-0.29038	-0.34546	1.00000	-0.67437		

ROW 12

0.56296	0.23199	-0.67631	-0.45711	-0.09576	0.58736	0.62831
0.47475	0.12977	0.23298	-0.67437	1.00000		

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